

# DESIGN OF COGNITIVE WORK SUPPORT SYSTEMS FOR AIRLINE OPERATIONS

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# DESIGN OF COGNITIVE WORK SUPPORT SYSTEMS FOR AIRLINE OPERATIONS

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*To Keith and Kathy*

*whose support, inspiration, and humor were never in short supply.*

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# CHAPTER I

## INTRODUCTION & MOTIVATION

As in many domains, the safe and efficient management of an airline is a complex cognitive task involving many individuals working in close coordination. Of note are the Airline Operation Managers (AOMs) of typical major U.S. airlines who are responsible for the daily operation of large regions or fleets of aircraft, commonly with 40-50 flights departing every hour. They oversee daily operations that are often disrupted by weather, ATC delays and unscheduled maintenance and are responsible for implementing flight delays, cancellations, ‘aircraft swaps’ and the use of reserve crews to minimize the impact of such disruptions.

Airline operations strives to regulate the schedule of the aircraft, flight crew, and cabin crew within the airline. The AOMs operate within an environment in which:

- The overall goal of the work is to regulate some dynamic system,
- A series of activities are required to reach/maintain the overall goal,
- Individual activities are dependent on the outcome of previous activities,
- Task parameters are continuously changing in response to system disturbances, and
- Tasks must be accomplished in real time.

Airline operations (AO) is additionally interesting because of the current interest in expanding the use of optimization techniques in airlines to aid in day-to-day operations in addition to its traditional application in advanced planning. Specifically, there has been much interest in the operations research (OR) community on using mathematical programming to improve airline recovery from irregular operations [8]. The aim of these algorithms is, first, to generate a set of feasible solutions, and, second, select the solution that optimizes some aspect of the operation, be it aircraft utilization, the number of passengers stranded or a composite function of revenue generation based on the problem description that it is given. With over 10% of daily operations considered to be irregular, even small performance improvements in AOMs’ performance could potentially save a significant amount of revenue. What is lacking is a coherent support system by which AOMs may consider the results of these algorithms relative to their immediate situation.

To date, most support systems have been fielded in static or slowly evolving dynamic environments. In these environments the challenges facing support system designers include dealing with uncertainty in situation assessments. Dynamic environments add a wide range of time constraints within which actions must be taken, as well as interdependence between subsequent decisions.

Further questions imposed by the inclusion of a human operator, which include:

- Which activities should the support system aim to support?
- What model of decision making, judgment, etc. should the system aim to support?
- How should the work be split between the human operator and the support system?
- How should the human and the support system interact?

Traditionally, support systems have been developed to aid in the comparison of multiple decision alternatives based on a set of attributes. These systems have focused on aiding the operator to make the best decision possible based on a model of rational decision making, and were thus dubbed Decision Support Systems. Sophisticated DSS can allow for the weighting of attributes and the automatic calculation of the “best” rational choice according to these weightings.

In the field of airline operations, there has been much interest in creating a DSS where the emphasis is not only on choosing between options, but also on generating feasible or “optimal” options [65] where the step of choosing between options is eliminated and the “best” solution is presented to the user to approve and implement. This can create an ‘authority responsibility double-bind’ [103]: the user has responsibility for the decision but may not have the resources to evaluate and improve the solution’s efficacy or to catch any problems [102]. In addition, as DSS are currently designed, this method of human-machine interaction takes time, suitably formatted information, and expertise. Unfortunately, time and suitably formatted information are not always available in environments such as AO. Often information that is necessary to “optimally” solve a problem is not known, not known precisely enough, or in a form difficult to enter in a DSS. In the case of traditional support systems, the designer chose to primarily support the activities of decision making and information gathering. The designer used a rational model of decision making, split the

work such that the human serves as an automation translator and monitor, and limited interaction between the humans and support systems to a minimum.

Research included in this thesis employs an ethnographic technique, ‘contextual inquiry’ as described by Beyer & Hotzblatt [2], to model the work performed by AOMs [21]. The contextual inquiry reveals that AOMs’ approaches to their work can vary widely. On a day with few disruptions the AOM may consider many possible alternatives to minimize flight delays. He may consult his colleagues, generate several alternatives and choose between them. Alternatively, on a busy travel day with major disruptions, the AOM may resort to broad measures such as operating his entire fleet an hour behind schedule. Observing these variations lead me to hypothesize that any tool intended to support AOMs’ work processes needs to accommodate the range of behaviors uncovered in the contextual inquiry. Unfortunately, traditional support systems do not accommodate different patterns of behavior observed, including different decision making strategies.

In summary, the current models and assumptions upon which support systems are designed is not appropriate for dynamic work environments such as AO, and are not consistent with the activities observed there. For example, present AO support systems focus on supporting decision making behavior alone. Further, DSS design is based solely on a model of rational decision making [65].

### ***1.1 Expanding the System Boundaries***

A new way to approach the questions present in the design of support systems for dynamic systems is to expand the boundaries of the system to include the human operator. In this way, we can then view the human’s work as the regulation of two dynamic systems simultaneously, i.e., the internal system (themselves) and the external system, i.e. in AO, the flight schedule. Adopting this approach allows us to confront the challenges which affect both the human and the system simultaneously by examining the contextual aspects which are hypothesized to be an underlying determinant of the choice of human performance.

Over the past few decades, there has been a steady shift in the study of human cognition away from the notion of cognition as a process control system towards a view of cognitive

control [35,42]. In the former, actions and behaviors are determined by the inherent structure of the activity, whereas in the latter “the control of the activity is determined by the sequence of cognitive goals; the sequence of cognitive goals is, in turn, determined by the context: the environment and the previous development” [42].

Traditionally, analyzing human behavior was based on an mechanical system analysis where behaviors of interest were broken down into atomic behaviors, such as judgment, and studied individually [41]. The intention was to understand each of these atomic behaviors individually, which would, in turn, allow predictions to be made about their collective performance. For example, the past 50 years of decision making research has revealed much about the nature of decision making (DM) and both the task and contextual aspects of DM that effect the DM process [4, 5, 48, 57, 58, 68, 80, 93].

However, if we take decision making as an example of one, well studied, atomic behavior there is growing evidence that individuals employ different decision strategies in response to context. Although the ‘when’ and ‘why’ these different decision strategies are used is still the subject of much interest, it has recently been suggested that contextual factors (such as perceived time limits and information availability) may have a large influence over decision strategy selection [57, 94, 95].

One contextual factor which has been identified is time pressure. Examining the effect of time pressure on decision making, it is generally believed that the greater the time available the better the decision will be. Maule and Edland stated, however, that there is relatively little evidence supporting these beliefs [5]. Their sentiments have been further echoed by Johnson, Payne and Bettman who concluded that “heuristics, under time constraints, may be even more accurate than a ‘normative strategy’. [80](p103)” Maule and Edland concluded that the effects of time pressure on performance depended crucially on the decision strategy adopted and its appropriateness to the situation [5]. This evidence suggests that the performance of the decision made may be more dependent on the decision strategy adopted than time pressure alone.

Consequently, there is a demonstrated need to support not only multiple decision making strategies, but, if this trend generalizes to other behaviors (i.e. judgment, information

gathering, coordination, communication, etc.), then there is a corresponding need to support multiple strategies for them too. Further generalizing, not only may the behavior strategies change in response to context, but the patterns of activities which govern the choice and timing of individual behaviors may also change.

Supporting different patterns of activities in response to context presents a number of questions. First, what are the important contextual features? Second, how do these contextual features affect behavior? Finally, how should a support system be designed to support such a wide variety of behaviors? Answering these questions is a key contribution of this thesis.

## ***1.2 COCOM as a Framework for Support System Design***

Let us examine in detail the idea of cognition as control, an idea examined in depth by Erik Hollnagel [40, 42–44]. The concept of cognition as control represents a fundamental break with the traditional notion that cognition can be viewed as an information processing system [12]. The information processing model assumes that human behavior can be modeled as a series of actions carried out in a predefined order. Unfortunately, this method has proven inadequate to account for the complexity found in sociotechnical systems [41, 86].

The next generation of models of cognition have consequently eliminated the idea that atomic behaviors are linked together in a specific manner. Instead, the Contextual Control Model (COCOM) states that the pattern of atomic behaviors are determined not by any inherent relation between themselves, but rather by the context. “In contrast to the information processing view, [COCOM] focuses on the functions deemed necessary to explain orderly performance and is intended to be applicable to a range of systems, including individuals, joint cognitive systems, and complex social-technical systems” [43] (p9). Accordingly the pattern of atomic behaviors can, and are anticipated to, change depending on context.

A specific instantiation of a COCOM has been described by Hollnagel as containing three elements. The first is a model of competence; the second is a model of control; and the third is constructs [42]. Of most interest for the design of support systems which support

a wide pattern of behaviors is the model of control.

This thesis postulates that the AOMs utilize different patterns of activity establish requirements for support systems into dynamic environments, such as Airline Operations. The model of control devised by Hollnagel as a part of COCOM provides a useful framework to view the changes in patterns of activity in response to contextual features such as time limit or information availability [42].

The model of control envisions the degree of internal control an individual has over a situation as a “continuous dimension where at one end there will be a high degree of control and at the other there will be little or no control” [42]. Hollnagel noted four contextual control modes along this continuum:

- “Scrambled control denotes the case where the choice of next action is completely unpredictable or random.” (p168)
- “Opportunistic control corresponds to the case when the next action is chosen from the current context alone, and mainly based on the salient features rather than durable goals or intentions.” (p169)
- Tactical control is characteristic of situations where “the person’s event horizon goes beyond the dominant needs of the present, but the possible actions considered are still very much related to the immediate extrapolations from the context.” (p170)
- “Strategic control means that the person is using a wider event horizon and looking ahead at higher level goals... The strategic control mode should provide a more efficient and robust performance, and thus be the ideal to strive for.” (p170)

An important aspect of Hollnagel’s model of control is the idea that individuals will transition between CCMs to maintain control over a dynamic situation [47, 92]. Several factors are thought to influence transitions between CCMs, including expertise, knowledge, situational awareness and system interface (ease of information access). According to the COCOM, a major contextual feature governing an individual’s choice of CCM is the subjectively available time.



### ***1.3 Implications/Designing for Multiple Control Modes***

Building on the great diversity of models of component actions, including judgment and decision making, COCOM accounts for many different patterns of behavior and many different ways of approaching a high level task. This breadth is necessary because the observation of airline managers detailed in this thesis revealed a wide variety of approaches to the overall task of schedule adherence, including not just how to make a decision, but also which decisions to make, which patterns of communication, coordination, and information seeking to employ, and when and how to apply these actions. Using the framework provided by the COCOM suggests that support systems could be tailored for specific CCM [22, 49, 73].

Schedule adherence in AO is a high level cognitive activity which includes behaviors such as perception, situation assessment, communication, coordination, analysis, alternative generation and comparison of alternatives, all organized by the worker's internal control [75]. The CCMs predict how each of these activities might change under different contexts. For example, an AOM operating in an opportunistic mode, where the choice of next action is often heavily influenced by the salient features of the environment, may need the interface to highlight the most relevant information in the environment and then facilitate task execution (in our test case, perhaps identifying the most imminent flight that is 'in trouble' and providing 'one-click' mechanisms to delay or cancel it). On the other hand, an AOM operating in a tactical mode may want their interface to support a common procedure for planning and double checking their task solution. Finally, an AOM operating in a strategic mode may want their interface to support solution comparison along a number of objective function lines (such as the number of passengers disrupted, number of aircraft disrupted, or overall economic impact) in addition to supporting task execution and solution checking.

Specific atomic functions may dominate the patterns of activity observed in the different CCMs. For example, the strategic mode may be dominated by decision making, especially the kind of rational, compensatory decision making described by multi-attribute utility theory. Similarly, the Tactical CCM may be dominated by procedure following behaviors, where the decision making just falls out of the procedure and is not really the focus of the work. Further, the Opportunistic CCM may be dominated by judgment and other situation

assessment activities, driven by the salient features of the environment.

## **1.4 Hypotheses**

This thesis asserts that cognitive work support systems (CWSS) can and should be tailored for specific contextual control modes. The underlying assumptions are, therefore, that (1) the concept of a contextual control mode is useful to engineers because it is a representation of a specific pattern of activity for which they can establish a design requirements and that (2) by understanding the patterns likely to be experienced by users in each CCM, engineers can design support systems appropriate for the context in which they will be used.

Specific hypothesis based on these assumptions state that AOM performance will improve when the support system better supports the contextual control mode used by the AOM. Thus when the AOM's CCM matches the CCM for which the support system was designed, it is hypothesized that the AOM's overall performance will be higher than if the AOM's CCM did not match the CCM for which the support system was designed. A corresponding secondary hypothesis is that support systems can be tailored to support different cognitive work behaviors and strategies.

Implicit within these hypotheses are these assumptions:

1. Different CCMs can be induced by the use of different time limits
2. CCM can be accurately measured through survey instruments
3. High levels of performance can be achieved in any CCM if it is appropriate to context
4. The Contextual Control Model accurately describes the organization of the pattern of behaviors comprising cognitive work

To summarize the thesis contains two conceptual hypotheses and three testable hypotheses:

1. CCM is useful to engineers as a representative pattern of activity
2. CCMs can be used to design support systems
  - (a) AOM performance will be better with CWSS designed to match the AOM's CCM than with a CWSS with a mismatched design
  - (b) Performance will improve with matching CCMs regardless of CCM used
  - (c) The pattern of behavior for each CCM will be distinctive

## **1.5 Contributions**

The research contained in this thesis provides three distinct contributions:

1. A theoretical foundation relating CCM to engineering design.
2. A basis for design of a CWSS using CCM, including methods of assessing CCM.
3. Demonstration of these benefits of CCM in a relevant domain.

First, this thesis creates a prototype CWSS for airline operations by augmenting the contextual design method developed by Beyer and Holtzblatt to accommodate the three higher level CCMs. Second, to assess the individual's operational CCMs, a survey instrument to measure individual CCMs will be created and implemented. Because, methods of directly asking individuals to self-asses their CCM are susceptible to biases caused by culturally perceived norms of problem solving, it is hoped that an indirect survey instrument will yield more consistent and potentially more accurate results. However, it is beyond the scope of this thesis to thoroughly validate the CCM survey instrument. Finally the hypotheses are assessed by evaluating the resultant CWSS prototype.

## **1.6 Thesis Overview**

The thesis is divided in to 8 chapters, as shown in Table 1. This first chapter has provided introduction and motivation for the thesis. The next chapter, Literature Review, provides background information required to understand the relevant theory including the Contextual Control Model, evolution of decision making theory and airline schedule recovery. Chapter 3 will present the results of a simplified preliminary experiment. Chapter 4 focuses on understanding and visualizing the work, and includes the contextual inquiry and the work models for the current airline operation practices. It contains the results of the contextual inquiry and the resultant work models.

Chapter 5 will focus on the work redesign, and creation of storyboards to describe the new work practices for each of the three CCMs. Chapter 6 will include the creation of the User Environment Design and Prototype creation; it will discuss the different aspects of the CCMs, and suggest implications of each of these aspects on the functions required of a CWSS. Chapter 7 will present the results and analysis from the final experiment. Finally,

**Table 1:** Proposed Thesis Organization

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Chapter 1	Introduction and Motivation
Chapter 2	Literature Review
Chapter 3	Preliminary Experiment
Chapter 4	Understanding and Visualizing the Work
Chapter 5	Work Redesign
Chapter 6	Cognitive Work Support System – Prototype Design
Chapter 7	CWSS Assessment
Chapter 8	Conclusions

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Chapter 8 will conclude the thesis with a discussion of the implications for future designs of CWSS.

## CHAPTER II

### LITERATURE REVIEW

To date most research conducted on cognitive work has focused on breaking human behavior into its atomic parts or functions and then proceeded to focus on these individual functions in isolation. Examples of these functions include judgment, decision making, perception, attention, and coordination.

The literature is full of good work in all of these areas which has helped us understand each of these atomic functions. This thesis, however will focus on using the Model of Control from a Contextual Control Model as a framework within which to harness this understanding and apply it to the design of cognitive work support systems. Before beginning, however, it is important to touch on the evolution of decision making theory which has led to the hypotheses stated in Chapter 1. The first section of this chapter, details how what is commonly called ‘decision making’ can encompass a narrow or broad set of behaviors. The second section introduces cognitive control models of behavior, and argue why they are an appropriate lens through which to analyze cognitive work. The third section reviews decision support systems and illustrates their impact on decision making performance in specific and cognitive work in general. The fourth section reviews measurement techniques for mental workload. The final section briefly describes on different approaches to airline schedule adherence and recovery.

#### ***2.1 Evolution of Decision Making Theory***

##### **2.1.1 Definitions**

The term decision making will, to most people, encompass the entire range of behaviors which go into making a decision. Such activities might include: perception, situation assessment, judgment, communication, coordination, analysis, comparison of alternatives, alternative generation, choosing amongst options, etc. However, a quick review of the decision making literature will reveal that most of the research on DM has been focused on

a narrow subset of the rich set of behaviors listed above. According to Orasanu and Connolly [75] traditional DM research has focused on only one part of DM which they refer to as the *decision event*. In keeping with the majority of the literature, decision making will be defined in this thesis as a choice between options. To better describe the range of behaviors which have been described above as the natural decision making process, this thesis uses the term ‘cognitive work’. Cognitive work is defined here as the broad set of activities which includes decision making, judgment, coordination, information gathering, solution generation, decision execution, etc. Additionally, judgment is an integral part of cognitive work, and is a distinct behavior and is defined in the literature and this thesis as the assessment of some criteria within the environment.

### **2.1.2 Decision Strategies**

The research into DM has led to the discovery and universal acceptance that individuals may employ any of a number of different DM strategies [5, 12, 80, 81, 93]. These strategies include, but are not limited to: weighted additive (WADD/SEU/MUAT), equal weight (EQW), satisficing (SAT), lexiconographic (LEX), eliminations-by-aspects (EBA), majority of confirming dimensions (MCD), frequency of good and bad features (FRQ) [81]. A central distinction between the different CBO strategies is how much they depend on making tradeoffs between attributes. DM strategies which make tradeoffs between attributes are considered compensatory, because a deficit in one attribute can be compensated for by a surplus in another. On the other hand, DM strategies which do not make explicit tradeoffs between attributes are considered non-compensatory [38]. Other distinctions include consistent versus selective processing, alternative-based versus attribute-based [81].

Distinctions have also been developed for DM strategies. A central distinction between DM strategies, relevant to dynamic decision making environment, classifies them into either action-oriented v. judgment-oriented strategies [57]. A judgment-oriented strategy is one in which the decision maker first chooses to assess the situation by seeking information and selects the most appropriate action second. Conversely, an action-oriented strategy is one in which the decision maker first implements an action, and then uses feedback from the system

to determine if further action is necessary. In general individuals seem to prefer (even to their detriment) a judgment-oriented strategy [57].

However, the debate still continues as to why individuals choose different DM strategies [68]. In an effort to answer this question, characteristics which differentiate one decision from another have been adopted by the research community and cited in the literature [81]:

**Task Effects** include task complexity, response mode, and information display. As task complexity increases, the literature consistently demonstrates that decision makers selectively attune to information and shift their CBO strategies toward simpler, non-compensatory strategies. Both response mode and information display have a clear effect on DM, however, “the relative magnitudes of all the effects and how they may interact when placed into conflict is not known” [81].

**Context Effects** include similarity and quality of the option set, reference point and framing effects. Research into reference point effects has revealed a status quo bias in which, similar to a loss aversion bias, leads decision makers to favor alternatives which do not lead to losses or a change in the status quo. Research into confirmation bias also suggests that individuals are more likely to seek out evidence that supports their conclusion than evidence that contradicts it. Additionally framing effects have been shown to affect DM which violate the normative principle of descriptive invariance” [81].

In addition to these two effects, I have added Time Pressure, which has been shown to have a significant effect on not only the decision strategy chosen, but also the decision quality [80,81]. The role of time pressure is described below and will be explored in greater depth in Section 2.1.4.

**Time Pressure** The literature has shown that as time pressure increases decision makers tend to adapt by being more selective in the information they consider. Under severe time pressure, they shift toward non-compensatory strategies. Additionally, decision makers appear adapt to time pressure in stages: first acceleration and filtration and then strategy shifting [80,93].

### 2.1.3 Decision Making & Performance

Over the past 50 years much work has been undertaken to better understand DM and judgment in an effort to improve task performance or task accuracy [5,48,57,59,68,80,93]. Unfortunately, it is not necessarily true that better decisions lead to better outcomes. Accordingly, objectively assessing decision quality demands assumptions regarding the relationship between decision quality and decision outcome.

The three prevailing benchmarks for assessing decision quality, which is defined in the literature as *decision analysis*, are [5]:

1. decision outcome
2. consistency of choice [11]
3. the amount of time allowed for the decision
4. (inverse) the mental effort required to reach a decision

Each of the above methods has strengths and weaknesses, according to the assumptions upon which it depends. The first and second method assumes on that decision outcome and consistency of choice can be equated to decision quality. The third method assumes that the more time a decision maker has the more attentional and cognitive resources she will use in an effort to maximize the accuracy of her decision [80,93]. This case is often linked to a belief that the more compensatory a decision strategy chosen the better the decision outcome [5]. The fourth method assumes that the greater number of mental operations required to make a decision, the more thorough the analysis and consequently the better quality the decision [5].

The methods described above are all related through the use of a normative, rational model of decision making such as described by Keeney and Raffa [56]. Corner and Craig characterize decision analysis as “a quantitative methods for analyzing decisions based on the ‘axioms of consistent choice’ ” [11]. Unfortunately, “normative theories do not tell us how people actually make decisions, but provide formal methods for researching optimal solutions,” and similarly “serve as a benchmark for evaluating the rationality of people’s unaided decisions” [75] (p16).

Over time, these associated normative models and underlying assumptions have been repeatedly called into question [12,30,80,93]. Johnson et al. simulated a variety of DM strategies and concluded “when faced with severe time constraints, a quick but incomplete evaluation of all the alternatives may lead to a better choice, on average, than a complete evaluation of a small subset of the alternatives that must be truncated when time runs out.” This result comes with the caveat that, although a general heuristic may do well in a specific task environment, there is no guarantee that the heuristic will perform similarly in all task environments. “For decision a maker to do well when using heuristic choice rules,



he or she needs to both (1) possess a repertoire of efficient heuristics and (2) know the conditions under which each heuristic will be efficient” [80] (p107).

#### **2.1.4 Decision Making and Time**

The vast majority of decisions are taken under some form of time pressure. Subjectively available time (SAT) has a unique role in decision making behavior. Maule and Edland recently reported on two studies that provided evidence that it is not “the actual amount of time but the individual’s appraisal of it that is critical in determining underlying cognitive strategy” [68]. Depending on whether the DM process is static (situations where only one decision is being taken and the necessary information is available at the point of choice) or dynamic (situations involving several decisions taken in a continuously evolving context), the concept of subjectively available time can either be viewed as simply a deadline, or as a series of deadlines which are additionally coupled with the development of the evolving situation itself [57]. In either case, the presence of time pressure has been shown to cause shifts in DM strategies [48, 68, 80, 93]. In general there is still much debate about the reason for these shifts and the mechanisms by which they work; however, there is a general consensus about the nature of strategy changes in response to time pressure.

Maule and Edland, in a recent review of the DM literature, have identified three broad methods of adapting to time pressure [68]. Two are considered micro-strategies as they require relatively minor changes in cognitive processing and are identified as acceleration and filtration. Acceleration requires an increase in the speed of activity associated with information processing and the minimization of pauses, rests or other interruptions in the DM process. Filtration indicates a reduction in the proportion of total attribute information or number of alternatives that are processed. The third method is considered a macro-strategy as it requires a major changes to the underlying cognitive process and is identified as switching from a compensatory strategy to a non-compensatory strategy, in addition to an increased use of attribute-based rather than alternative-based processing [68].

Maule and Edland further state that, although there was a general assumption that time pressure reduced the quality of decision making, there has been relatively little evidence

supporting these beliefs [68]. Their sentiments have been further echoed by Johnson, Payne and Bettman who concluded that “heuristics, under time constraints, may be even more accurate than a ‘normative strategy” [80](p103). Maule and Edland concluded that the effects of time pressure on performance depended crucially on the strategy adopted and its appropriateness to the situation [68].

In this thesis I define decision time horizon (DTH) as the time available to assess the situation (including all information gathering), generate alternatives, choose between the alternatives (if more than one alternative has been generated)/ make the decision and execute the decision. Note that the above definition describes the DTH as a contextual feature of the environment and not of the decision. Distinct from DTH is the concept of subjectively-available time (SAT). Maule and Edland have shown that performance can be correlated with SAT, but not with DTH alone [68]. It is hypothesized that if a person has some expertise in the task, their SAT will be well attuned to the DTH, and that the design of support system may aid or hinder this attenuation.

### **2.1.5 Naturalistic Decision Making**

An important emergence in the evolution of decision making theory has been the emergence of a classification of decision making analysis known as Naturalistic Decision Making (NDM). The interest in NDM approach has its roots in a variety of sources [46, 61, 71, 86]. First, there was an intellectual curiosity by a number of researchers as to how individuals actually made decisions under stressful conditions characterized by time pressure and information uncertainty. These stressful conditions naturally lent themselves better to field studies than laboratory experimentation. Second, many research sponsors were interested in understanding decision making in real-world settings. And, lastly, basic and applied researchers attempted to generalize of many research findings outside the laboratory setting, and found it difficult to do so [61, 75, 83]. Instead, they discovered a growing body of evidence indicating that decision performance was not following the normative models of classical decision making. As Orasanu aptly stated, “the complex world is not just an aggregation of the simple. Certain reasoning processes emerge only in complex environments,

and are not available for study in simple tasks” [75] (p15).

The decision making sciences seem to be undergoing a paradigm shift away from classical decision making (CDM) toward NDM. Rasmussen observed, “The classic decision theory was a normative theory developed by economists and mathematicians (von Neumann & Morgenstern, 1944). The emphasis is not on what decision makers actually do, but what they should do” [86] (p77). This normative theory was then followed by psychological decision theory as typified by Tversky & Kahneman in 1974, which describes the behavior of practical decision making by augmenting normative theory with the concepts of biases and heuristics. Psychological decision theory sought to explain human behavior by its deviation from rational behavior or, in other words, in terms of error. In these two paradigms decisions were discrete events which could be isolated and analyzed. Presently, however, judgment and decision making are not being viewed from the standpoint of error reduction, but instead in terms of response to context and are increasingly being considered as a “continuous control task” [86]. This paradigm shift has brought about the distinction between CDM and NDM.

NDM is defined as “the study of how people use their experience to make decisions in field settings” by Zsombok and Klein [61]. This definition is not very precise, and consequently a better understanding of NDM may be derived from the four criteria identified by Zsombok as differentiating NDM from CDM [34]:

<b>Task Features and Settings</b>	context-rich rather than context impoverished
<b>Nature of Research Participants</b>	experienced rather than novice
<b>Research Purpose</b>	discovering the strategies people use rather than detecting deviations from a rational standard
<b>Locus of Research Interest</b>	to include situation awareness rather than being restricted to the moment of choice

Additionally, Orasanu and Connolly [75] created a list of eight factors that typify NDM:

1. Ill-structured problems
2. Uncertain dynamic environments
3. Shifting, ill-defined or competing goals
4. Action/feedback loops
5. Time stress
6. High stakes
7. Multiple players

## 8. Organizational goals and norms

The shift from normative models of CDM to the descriptive models of NDM has large implications for the design of socio-technical systems, which are rapidly proliferating in the modern world. One of the primary implications is that NDM models often describe multiple modes of behavior or multiple strategies of decision making, none of which is necessarily ‘better’ than another [12]. For example, in CDM a decision which was made using less than a full analysis of all attributes for each alternative, due to lack of adequate time to collect all relevant information, would be considered suboptimal. In contrast in NDM, given that there was limited time and information to make a decision, the quality of the decision the conclusions draw is likely to be lower than if time was adequate, but the reason was the unavailability of key data, not a degraded decision strategy [61]. NDM models include Rasmussen’s Skills/Rules/Knowledge, Klein’s Recognition Primed Decision Making, Mitchell’s Image Theory, and Montgomery’s Search for Dominance Structure [61, 85].

### *2.2 Contextual Control Models*

Modeling human behavior has always been a challenge [43, 60]. In the era of cognitive work, this truth remains for, while behavior during work should, by definition, seek to satisfy the overall system goals or objectives, it is often unclear when and how the work is accomplished. The ‘when’ and ‘how’ of cognitive work are completely at the discretion of the individual. According to Rasmussen,

The options of choice define a space of possibilities within an envelope bounded by the limits of functionally acceptable performance, by the limits of acceptable cost-effectiveness, and by the work load accepted by the individual. Within this space many degrees of freedom are left open for the individual actor to choose among strategies and to implement them in a particular sequence of behavior [86] (p27).

Historically, there have been three methods of modeling of human performance. The oldest is the stimulus-response approach, where humans were modeled as a time delay in

system dynamics models. This model has been largely replaced by an information processing model of human performance, where human performance is modeled as feedback control system. The information processing model assumes that human behavior can be modeled as a series of actions carried out in a predefined order. Unfortunately, both of these methods have proven inadequate to account for the complexity of human activity found in socio-technical systems [41, 86].

Instead, new models must be created which do not rely on the idea of a prescribed order of atomic behaviors. One type of model which meets this criteria is the Cognitive Control Model. A cognitive control model implies that actions are determined not by any inherent relation between themselves, but rather by the context. It is a way of modeling cognition in terms of contextual control rather than procedural prototypes [42]. “In contrast to the information processing view, the COCOM focuses on the functions deemed necessary to explain orderly performance and is intended to be applicable to a range of systems, including individuals, joint cognitive systems, and complex social-technical systems” [43] (p9).

The COCOM devised by Hollnagel contains three elements. The first is a model of competence. The second is a model of control, and the third is constructs [42]. The model of competence consists of the set of possible actions (action set) a person may choose to implement at any moment in time and the patterns for carrying out the actions (template set). The patterns defined in the template set, “may be plans (pre-defined or produced during the task), procedures, rules, guidelines (heuristics), strong associations, or in fact any thing else that may serve as a guide for performance” [42].

In the COCOM the pattern used is determined by the model of control. Control in this model is conceptualized as planning what to do in the short-term and within the time horizon of the system with which the human is interacting [43]. The control model consists of a continuum of control, where at one end there is little to no control, and at the other there exists a high degree of control.

To describe this continuum of control, Hollnagel developed a classification that describes how humans organize their activities. The classification contains four contextual control modes (CCMs) that are characterized by the seven performance characteristics shown in

Table 2. These characteristics include the number of goals, subjectively available time, selection of next action, and evaluation of events [42]. For completeness the definitions of each CCM given in Chapter 1 are repeated here:

**Scrambled control** “denotes the case where the choice of next action is completely unpredictable or random... This type of performance is thus, paradoxically, characterized by the lack or absence of any control” [42](p168). Examples of scrambled control include individuals in a state of panic or complete indecision.

**Opportunistic control** “corresponds to the case when the next action is chosen from the current context alone, and mainly based on the salient features rather than on more durable intentions or goals” [42](p169-170). In this mode planning and anticipation are limited often because of limited constructs or limited time.

**Tactical control** “is characteristic of situations where the person’s performance is based on some kind of planning, hence more or less follows a known procedure or rule. The person’s event horizon goes beyond the dominant needs of the present, but the possible actions considered are still very much related to the immediate extrapolations from the context” [42](p170).

**Strategic control** “means that the person is considering the global context, i.e., using a wider event horizon and looking ahead at higher level goals... The strategic control mode should provide a more efficient and robust performance, and thus be the ideal to strive for” [42](p170).

The third COCOM component is constructs. Constructs refers to what the system assumes or knows about the current context. The term constructs is used to emphasize their artificial nature – as they are the temporary constructions of the salient aspects of the situation. They form the basis for interpreting information and selecting actions [43].

An important aspect of Hollnagel’s COCOM is the idea that individuals will transition between CCMs to maintain control over a changing situation [47, 92]. Hollnagel states that “the change between control modes is determined by a combination of situational and person (or internal) conditions - in other words by the existing context” [42](p194). Several factors are thought to influence transitions between CCMs, including expertise, knowledge, and system interface (ease of information access).

Of most interest here is subjectively available time, although many factors maybe subsumed into this [42]. If the subjectively available time is short, actions will tend to be in the ‘opportunistic’ CCM. However, if subjectively available time is greater an individual will begin to seek additional information, evaluate alternatives, or execute procedures and

**Table 2: COCOM Contextual Control Modes**

	Strategic	Tactical	Opportunistic	Scattered
Number of Goals	Several	Several (limited)	One or two (competing)	One
Subjectively Available Time	Adequate	Adequate	Just adequate	Inadequate
Selection of Next Action	Prediction based	Procedural	Association based	Random
Evaluation of Events	Elaborate	Normal details	Concrete	Rudimentary
Event horizon	Extended	Normal	Narrow	None
Plans Available	Pre-defined or generated	Available and used	Negligible or limited	None
Execution mode	Mix of subsumed and feed-back	Feedback (with comparison to expected outcome)	Feedback (with observation of effects on system)	Subsumed

actions which correspond to the tactical CCM; if subjectively available time is perceived to be large, an individual will be able to fully explore the situation and evaluate all possible actions, which correspond to the strategic CCM. This impact of time pressure has been experimentally linked directly to COCOM control modes in dynamic tasks, by both Jobidon et al (2004) and this thesis with the conclusion who concluded that increased time pressure, i.e. less time to complete the task, corresponds to 'worse' COCOM control modes [29, 47].

In a recent empirical study, Stanton et al. (2001) concluded that not only was it possible to classify team behavior into the four COCOM control modes reliably but the transitions between modes (i.e., from strategic to tactical to opportunistic to scrambled and vice versa) were as COCOM predicted, providing what is believed to be the first independent test of the model [92].

In addition, the control mode must be appropriate to the context. An erroneous assessment of context, such as a poor assessment of subjectively available time, may lead to use of a CCM that will not result in the best performance possible in the available time. Thus, inappropriate use of a higher control mode may result in lower performance. For example, empirical studies by Johnson et al. and Oransanu found that mismatches between context and apparent decision strategies could have detrimental effects on performance [49, 75].

Unexpectedly, these mismatches can occur with reductions in workload, suggesting that CCMs and their appropriateness to the context can be better predictors of performance than workload measures alone. For example, in some cases increased time available resulted in a lower perceived workload without an increase in performance. Conversely, sometimes decision makers used a slight increase in time available to exert higher effort and higher performance control modes.

COCOM was of interest in this work because it provides a framework under which different modes of a cognitive work support system can be envisioned to support each of the different contextual control modes. Supporting more than one CCM is important because of the variety of different patterns of behavior, including decision making strategies, that have been identified in the literature. It has been suggested that DSSs could be tailored for specific decision modes [22,49,73], and this thesis extends this speculation to encompass all aspects of cognitive work.

Building on the great diversity of models of component actions, including judgment and decision making, COCOM allows for many different patterns of behavior and many different ways of approaching a high level task. This breadth is necessary because observation of airline managers has revealed a wide variety of approaches to the overall task of schedule adherence, including not just how to make a decision, but also which decisions to make, which patterns of communication, coordination, and information seeking to employ, and when to apply these actions.

### ***2.3 Decision Support Tools***

Historically, humans have sought to improve system performance through the introduction of technology. In manufacturing, the introduction of technology to improve the performance of the factory was colloquially known as *automation* because of the way that machines automatically performed the job of a human being. In more cognitive work environments, the implementation of technology often took the form of a decision support system as the work being performed in this setting was classically termed decision making (although it incorporated many different behaviors such as judgment, information gathering, information



sorting, and coordination, as well as decision making).

### **2.3.1 History**

Decision support system (DSSs) came about through a combination of efforts from the Carnegie Institute of Technology on organizational decision making in the 1950s and the Massachusetts Institute of Technology on interactive computer systems in the 1960s [82]. DSS can be seen as the natural evolution of computer applications from electronic data processing to management information systems to decision support systems [55]. The early work on DSS is synthesized in a series of three books edited by Peter Keen and Charles Stabell on Decision Support. The first book written by Keen and Scott Morton in 1978, entitled “Decision Support Systems: An Organizational Perspective” [82], provided an early working definition of DSS as well as an overview of the work thus far on DSS. The second book focused on electronic meetings and has little bearing here. The third book by Alter (1980) entitled, “Decision Support Systems: Current Practice and Continuing Challenges,” set forth the first comprehensive categorization of DSS from data oriented to model oriented.

Keen and Scott Morton provided a comprehensive definition of DSS in which each term was individually broken down and which has been well summarized by Marakas in 1998 as, “a system under the control of one or more decision makers that assists in the activity of decision making by providing an organized set of tools intended to impart structure to portions of the decision-making situation and to improve the ultimate effectiveness of the decision outcome” [64]. Other early working definitions of DSS included “A class of information system that supports decision making activities” by Sprague and Carleson in 1982 [82]. As this thesis is primarily concerned with the human machine interaction aspect of a DSS, this thesis will adopt the Marakas’ definition of DSSs.

Marakas’ definition is a functional definition which does little to answer the question of how a typical DSS achieves this functionality. Over the past 30 years, while the applications to which DSS have been applied has expanded functional aspect of DSS, the typical make up of a DSS has been converging on a set of five subsystems which are listed below [64].

### **Components of a DSS**

- Data management system
- Model management system
- Knowledge engine
- User interface
- User

The data management system handles the retrieval, storage and organization of data for each decision event. The mode management system handles the organization, retrieval and storage activities which support the quantitative models which perform the analytical analysis for the DSS. The knowledge engine handles the problem recognition and solution generation activities of the DSS. The user interface handles the input of data from the user and the output of data from the DSS to the user. The user is the person for whom the DSS is designed to support and with whom rests the final responsibility of a decision.

### **2.3.2 Categorization**

The literature is full of case studies describing a wide variety of DSS implementations and as a result what managers, academics, consultants and vendors consider a DSS can “take on many different forms and can be used in many different ways” (Alter, 1980). This variety has in turn led to the creation a large number of classification schemes or frameworks used to describe DSS.

The first classification schemes were included in books written by Keen and Scott Morton and Alter. Keen and Scott Morton created a two dimensional framework based on Simon’s (1960) classification of decision structure (structured, semi-structured and unstructured) and management activity [55]. In 1980, Alter devised a framework for classifying DSS divided into 7 categories depending on the degree of direct influence of the data management system versus the model management system, independent of the problem type or functional application. In the 25 years since Alter’s framework, new DSS have been devised, such that Power suggests simplifying Alter’s taxonomy from seven down to three and adding new categories which categorize DSS in terms of intended users, purpose and enabling technology. While not all DSS systems will fit neatly into one category or another, most will be ‘driven’ by one aspect of the DSS category more than the others. Power’s expanded DSS framework is reproduced in Table 3.

**Table 3: Decision Support System Framework**

<b>Dominant DSS Component</b>	<b>User Groups: Internal, External</b>	<b>Purpose: General, Specific</b>	<b>Enabling Technology</b>
<b>Communications-driven DSS</b>	Internal teams, now expanding	Conduct a meeting, Bulletin board, Help users collaborate	Web or Client/Server
<b>Data-driven DSS</b>	Managers, staff, now suppliers	Query a data warehouse	Main Frame, Client/Server, Web
<b>Document-driven DSS</b>	Specialists and user group is expanding	Search web pages, Find documents	Web
<b>Knowledge-driven DSS</b>	Internal users, now customers	Management advice, Choose products	Client/Server, Web
<b>Model-driven DSS</b>	Managers, staff, now customers	Crew scheduling, Decision analysis	Stand-alone PC

### 2.3.3 Benefits

Decision Support Tools are of great interest to a wide variety of academic disciplines from computer science, behavioral science, to operational management because of their potential to empower individuals to make more effective and timely decisions [9, 33, 65, 87]. Marakas has compiled a detailed list of benefits derived from decision support systems, portions of which have been replicated below [64].

#### Decision Support System Benefits

- extends decision maker's ability to process information and knowledge
- extends decision maker's ability to tackle complex problems
- shorten time associated with making a decision
- improve the reliability of a decision process or outcome
- encourage exploration or discovery
- generate new evidence in support of a decision

In fact, modern DSS are often are tasked with improving their user's ability to correctly identify important information within in the environment and to translate that information into viable options as they help their users decide between pre-identified options.

### 2.3.4 Limitations

Despite the enormous advances made to DSS over the past thirty years, DSS do have limitations which are important to understand. A list of common DSS limitations is listed

below. This list was compiled from Marakas and Power [64, 82]:

### **Decision Support System Limitations**

- power of DSS depends on the computer system it is built upon, its design and the knowledge it possesses
- natural language processing is not yet supported by due to language and command interface limitations
- DSS are normally designed for a specific application and do not perform well outside of the scope of this original application

#### **2.3.5 Future**

The future will see the inclusion of decision support systems in an ever increasing number of domains. Additionally, it is postulated that DSS will expand to take on more aspects of cognitive work. Key challenges will center on gaining user acceptance or gaining an appropriate level of trust [70] and determining appropriate function allocation and level of automation [15, 50, 51]. In many situations this becomes a tradeoff in efficiency, robustness, and situation awareness [16, 18]. Further, the awareness of contextual influences has lead to the introduction of adaptive and adaptable automation, addition another layer of complexity [74, 77, 78]

### **2.4 *Airline Schedule Adherence and Recovery***

US airlines play a large role in the efficient operation of the national air transportation system, not only due to strategic decisions made by airlines, but also on the daily implementation of these strategic decisions [21, 84]. AOMs of typical major U.S. airlines oversee daily operations that are often disrupted by weather, ATC delays and maintenance problems and are responsible for implementing flight delays, cancelations, aircraft swaps and the use of reserve crews to minimize the impact of such disruptions. AOMs must make decisions in a variety of decision time horizons, frequently based on uncertain information. On average 10% of revenue generating flights are disrupted on a daily basis, leading to annual losses of over \$400 million per major carrier [8].

Previous research into airline operations has taken an operations research approach where schedule creation, crew assignments, aircraft assignments and route pricing have become progressively optimized as the advancement of computer computational power has

improved. This thesis advocates taking an additional ethnographic approach to better understand the work in AO before attempting to support it.

#### **2.4.1 Operations Research Approach**

Airline Operations have been the focus of Operations Research analysis. Presently, schedule recovery is handled manually by highly skilled individuals with years of airline experience. According to Clarke and Smith, however, “recent advances in mathematical programming and computer processing speed now enable researchers to consider solving real-time decision problems such as schedule recovery” [8].

Correspondingly, there has been much interest in the operations research (OR) community on creating support system which incorporates algorithms based on these mathematical programming methods. In these support systems the emphasis is on not only choosing between options, but also on generating feasible or “optimal” options [8, 65]. The aim is to generate a set of feasible solutions that seek to optimize some aspect of the operation. The second step of choosing between options is therefore eliminated (or conducted in the background) and the “best” solution is presented to the user to approve and implement.

Presently, several different companies, including Sita, m2p and Navitaire, make decision support tools for airline schedule recovery. Most of these products are only one of a suite of software products which began with schedule optimization, crew pairings and revenue management. As of 2005, at least seven airlines (Continental, North West Airlines, Southwest Airlines, Delta Airlines, JetBlue Airlines, United Airlines, and AeroMexico) had implemented recovery decision support tools. However, most of these airlines have only recently introduced these tools, so the tool design is far from mature. Clarke and Smith stated in 2003 that the optimization techniques required to perform real-time optimization of schedule recovery were only just becoming computationally feasible [8]. According to research by Navitaire, there were no fully integrated recovery products implemented at any airline [76]. Further, since 2005 at least one of the airlines above no longer uses a DSS to aid in recovery from irregular operations.

### **2.4.2 Ethnographic Approach**

A contextual inquiry is an interviewing technique described by Beyer & Hotzblatt which is centered on four guiding principles: context, partnership, interpretation and focus [2]. The first principle, context, implies that the interview must take place where the work is being conducted. Conducting the interview in context allows the interviewee's actions and their answers to questions to be much more accurate. The second principle, partnership, requires that the traditional role of interviewer-interviewee is replaced with the familiar role of mentor-mentee. This relationship enables the interviewee to take more control in the interview and thus impart the knowledge that they feel is important instead of simply answering questions specifically asked of them. The third principle, interpretation, signifies that a shared understanding must be developed about all aspects of work that matter. To accomplish this, the data collected must be transformed into meaningful information before it is useful. Contextual inquiries use a set of models to bring about this transformation. The fourth principle of focus implies that, unlike pure observation, contextual inquiry allows the interviewer to steer the conversation gently, to remain on task and to capitalize on unexpected insights. This thesis uses contextual inquiry to approach CWSS design for AO from an ethnographic perspective.

### **2.5 *Mental Workload Measurement***

Workload is often defined as a measure of the cost of completing an assigned task for a human, where costs include stress, fatigue, and the depletion of cognitive and attentional resources [31, 89]. Workload, as with many measures of human capabilities and responses contains a high degree of variability between individuals. This thesis is concerned only with mental workload. Research in workload has explored three main areas: 1) how best to assess workload experienced by a human [100]; 2) how best to assess the workload likely to be required to perform a task; and 3) how to predict performance based on a measure of workload.

The two primary theories of workload are the limited capacity or limited channel model [52, 53, 100] and the mixed parallel model which has both limited capacity and stage features

[54]. The mixed parallel model postulates that a source of limited capacity feeds both a response stage, which controls the output for all tasks involved, and at least two preceding stages, each associated with a single component task.

Measures of workload can be classified as either objective or subjective. There are two primary measures of objective workload: physiological and secondary task performance. Physiological workload measurements have the advantage that they do not directly affect the task under consideration, they provide objective measures and require no additional activity or performance by the subject. Their disadvantages include: general insensitivity and high, often subject-specific, variability. Some progress has been made recently though using EEG to measure workload, although this process still suffers from low precision [13,66,67]. Secondary task measures of workload have the advantage that they have a high face validity. Unfortunately their disadvantages include that tasks used in secondary tasks are not widely generalizable as the nature of the primary task significantly affects performance on the secondary task and that they may interfere with the primary task under consideration [98].

Subjective workload measures come in one of two varieties, a unidimensional rating scale or multidimensional rating scales. Sanders & McCormick (1993) consider subjective rating scales as capturing the essence of the workload concept better than the other workload measures. Examples of unidimensional workload rating scales include the Modified Cooper Harper which presents the user with a series of 10 questions to answer where a “yes” answer allows the user to move on to the next question, and a “no” answer terminates at a numerical score. The NASA TLX and the SWAT are examples of a multidimensional workload rating scales. Rating scales have the advantage of providing direct insight into the operator’s perspective on workload. Disadvantages include the fact that they are subjective by nature and may be biased by the subjects’ perception in how much workload a task should require. Subjective workload measurement techniques have been successfully used in a wide range of evaluations and have yielded high levels of sensitivity [98].

The NASA-TLX is a multidimensional scale with six dimensions: mental demand, physical demand, temporal demand, performance, effort and frustration [36,37]. The sub-scales are weighted by means of pair-wise comparisons of the sub-scales and used to provide a single

workload score. The TLX has been shown to be a highly sensitive instrument measure of workload and is widely used in aviation applications [96,98]. The raw sub-scales scores have also been used to good effect as a measure of workload [6,36]. This thesis uses the NASA TLX raw sub-scales to measure workload.



## CHAPTER III

### PRELIMINARY EXPERIMENT

#### *3.1 Motivation & Objectives*

This chapter presents a preliminary experiment investigating CCMs during a schedule adherence task. This experiment sought to verify the impact of time limits and a change in task demands on patterns of activities as described by COCOM control modes. Based on previous research findings [39, 49, 58], I expected that the selection of the most appropriate CCM - not necessarily the "highest" - would correspond to the best performance. Second, I sought to evaluate measures of CCMs, including a self-assessment and measure of information seeking behavior. The experiment was preliminary in nature because the task used was simplified and the participants were novices. The results have been published in the Summer 2007 issue of the Journal of Cognitive Engineering and Decision Making [29].

#### *3.2 Method*

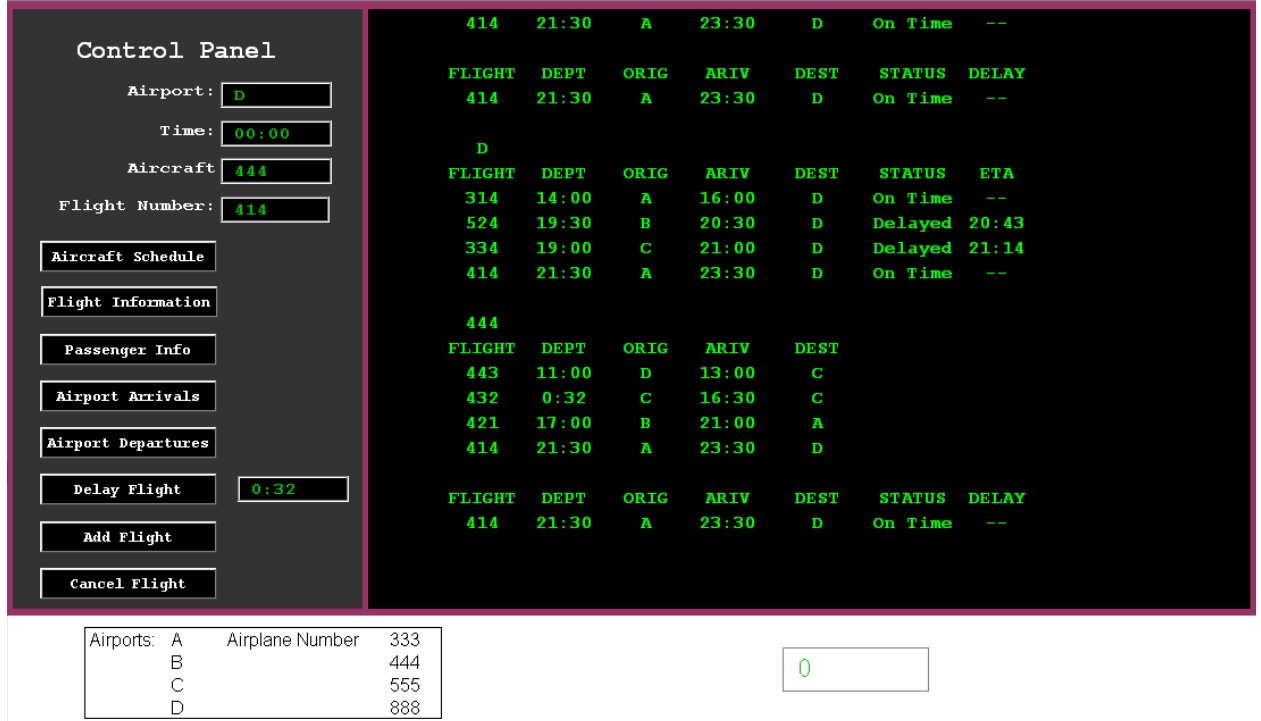
This experiment consisted of two parts. The first part of the experiment imposed time limits anticipated to correspond to different CCMs while recording potential CCM measures. In the second part of the experiment we introduced an unexpected disruption (increasing task demands) to evaluate its impact.

##### **3.2.1 Participants**

This study sought to examine AOM behaviors in a more controlled environment. Participants in this experiment were undergraduate students recruited from the course ISyE 2030, "Models in Industrial Engineering," in which they had received some instruction on logistics using airline operations as an example.

##### **3.2.2 Apparatus**

Participants used a standard computer terminal with keyboard, mouse, and a 17in. flat panel display. The computer display mimicked the text-based terminal windows currently



**Figure 1:** Experimental Apparatus

used by AOMs, as shown in Figure 1. However, to minimize difficulties in its use, command buttons were substituted for text-based commands. The participants were also given paper and pencil.

### 3.2.3 Experimental Task and Procedure

Participants were asked to assume the role of an AOM for a small airline. Each participant performed a training run which exposed them to a simplified task and familiarized them with the experimental task, computer interface and information available during the experiment. They were subsequently given feedback on their performance. Total training time was 45 - 60 minutes. The following five runs asked participants to find the best solution for the given scenario in the time provided.

In each scenario, participants were put in charge of four aircraft servicing four airports. Each aircraft was scheduled to fly between two and seven flights. Each scenario had a different disruption to its schedule, including decreased runway capacity and unexpected aircraft maintenance, which was explicitly stated in the explanation at the beginning of

each run. The participant’s task was to accommodate as many passengers as possible while satisfying some basic constraints (e.g., all flights must terminate by midnight) within a given time limit. The disturbances found in these scenarios are identical to those commonly found at airlines; the major difference is the complexity of the airline schedule, fleet and crew assignments. In the second part of the experiment, task demands were increased two minutes into the final run when a further disruption was suddenly introduced. At the end of each run, participants were asked to record their solutions and the number of passengers they believed their solution had been unable to accommodate, and to self-assess their workload and CCM.

The participants could access complementary computer-based and paper based information about the flight schedules. The paper-based information mimicked information normally obtained by communicating with other personnel that is beneficial but not absolutely necessary. For example, asking ‘when an aircraft would be ready’ mimicked communication with the maintenance department. A participant seeking this information was required to wait either 30 or 60 seconds to obtain it.

### **3.2.4 Experiment Design**

The first part of the experiment had three factors with four levels each: time limit, scenario, and run order. The following time limits were used: 18, 13, 8, and 3 minutes. These limits were selected through a preliminary investigation to create time pressures anticipated to correspond to a range of CCMs. The scenarios (labeled A-E), time limits, run order and participants effects were randomized using four different Graeco-Latin squares which combined to form a full factorial repeated measures design.

The second part of the experiment used a cross-over design with two factors with two levels each: increased task demand and scenario. The final run (i.e., the second part of the experiment) increased task demands, when an additional disruption was added without warning to the participants two minutes into the run. The time limit was fixed at eight minutes and contained the same scenario task between participants. The 8-minute time limit was anticipated to correspond to the opportunistic control mode from which transitions in

CCM could be observable in either direction. The disruption was always given in this final run so that participants would not anticipate such a disruption subsequently.

### 3.2.5 Dependent Measures

Measures included the following:

**Computer Interaction** Key logging and mouse tracking software recorded the participant's keystrokes and mouse usage. Computer interaction was represented by the frequency of distinct requests for information (FDRI).

**Interaction External to the Computer** External interaction was measured by the number of times the participant used external information, converted into a percentage by dividing the number of pieces of information actually used by the total number of pieces of information that were available, referred to as the percentage of external information used (PEIU).

**NASA Modified Task Load Index (TLX)** Workload ratings were collected after each run via the six NASA TLX subjective rating sub-scales: mental demand, physical demand, temporal demand, performance, effort, and frustration.

**Self-Assessment of CCM** At the start of the experiment, subjects were briefed about the CCMs using Hollnagel's description for each of the four modes. However, behaviors may fall somewhere in between two modes (e.g. tactical but leaning towards opportunistic). Accordingly, participants were given a scale of 1-10, where the four CCMs were explicitly labeled at the 1 (strategic), 4 (tactical), 7 (opportunistic) and 10 (scrambled) marks. Ratings of 1-2 were considered strategic, 3-5 tactical, 6-8 opportunistic and 9-10 scrambled; shifting from a 4 to a 3 on the scale would represent a transition towards strategic control. Additionally, participants were asked to describe if they felt that they had transitioned from one control mode to another during the run, including which CCM they had transitioned from, to, and what triggered the transition.

**Performance** Performance was derived from the participants' solutions. Each scenario was designed to have at least four valid solutions; participants solutions' were ranked relative to the valid solution set according to the number of passengers stranded and the number of flights canceled or delayed, the fewer individuals delayed, stranded and fewer flights canceled the better. For example a solution which delayed 50 individuals was preferable to a solution which stranded 50 individuals. The four best solutions were ranked one through four. All other valid solutions were given a rank of five. All invalid or non-existent solutions were assigned a rank of six.

### 3.2.6 Data Collection and Analysis

Each of the 16 participants conducted 5 runs, establishing 80 data points for most measures. Significance and marginal significance were set at the  $\alpha = 0.05$  and 0.10 levels respectively. When the dependent variable data could be classified as interval data, (e.g. the NASA TLX scales), general linear models and linear regression analysis were used. For the general linear models (GLM), time limit, scenario, and order were included as fixed effects and the participants were included as a random effect. Unless otherwise noted, run order, scenario and their two-way interaction with time limit effects were found to be not significant. Where general linear models and linear regressions were not appropriate (due to data type or lack of residual normality) non-parametric analyses were used as indicated.

## 3.3 Results

### 3.3.1 Experiment Part 1: Varying Time Limits

The first portion of this experiment examined the effect of time limits on participants' performance, self-assessed CCM, computer interaction, interaction external to the computer, and workload (as measured by the NASA TLX). A GLM found that FDRI  $F(3,39) = 10.94$ ,  $p < 0.001$ , TLX temporal  $F(3,38) = 13.24$ ,  $p < 0.001$  and TLX frustration  $F(3,39) = 4.26$ ,  $p = 0.011$  were significantly affected by time limit; as the time limit was increased from 3 to 18 minutes, all three measures decreased significantly. For the TLX frustration subscale, scenario was also found to be a significant  $F(3,39) = 22.94$ ,  $p = 0.001$  contributor, as one scenario had a perfect solution (in which no passengers were stranded) which was reported

as being significantly less frustrating.

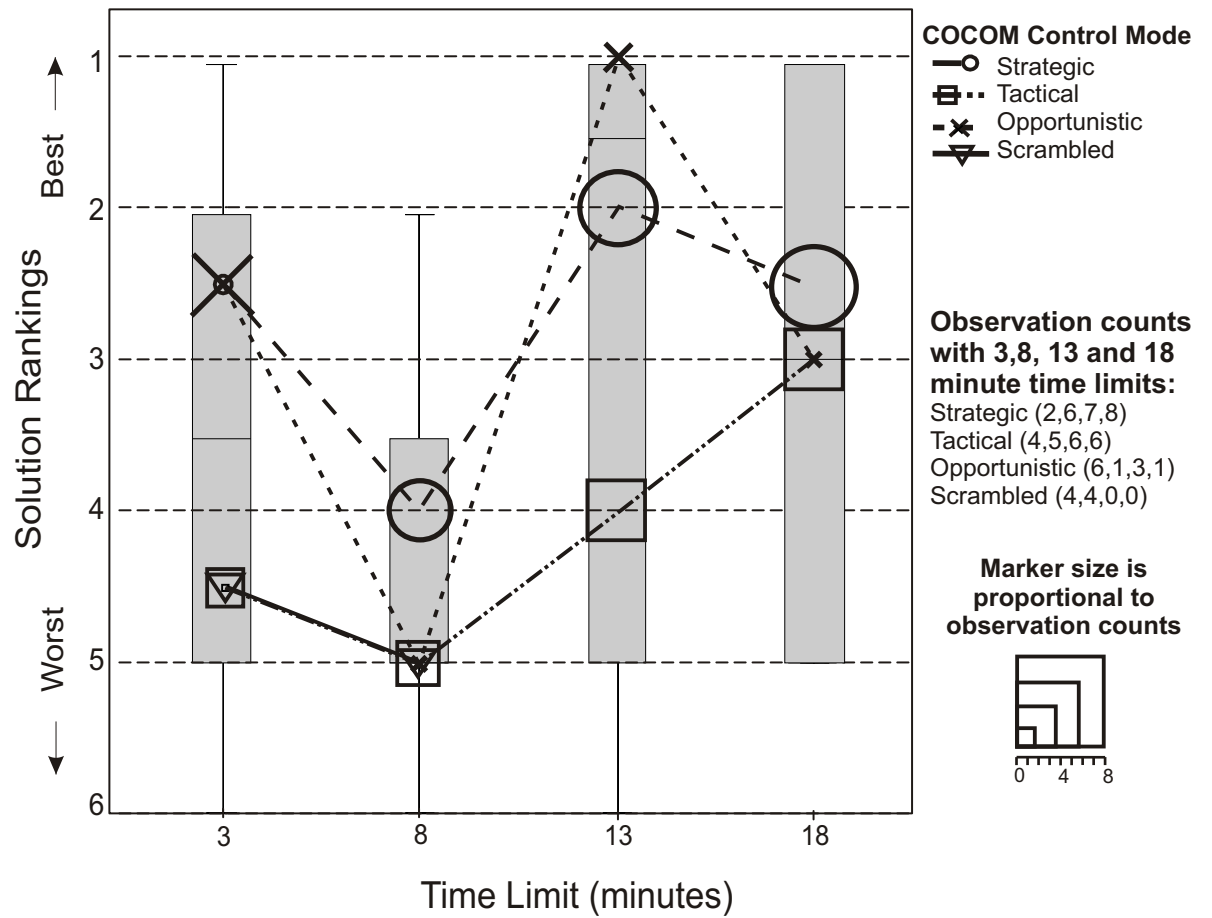
A Friedman's two-way ANOVA by ranks revealed a marginally significant effect of time limit on CCM  $F(3,39) = 2.476$ ,  $p = 0.054$  but no significant effect on performance. As the time limit was increased, a higher percentage of subjects reported being in a strategic CCM.

Two of these results merited further investigation. First, time limit had no significant statistical effect on performance. Second, the only TLX subscales to significantly vary with time limit were the TLX temporal and TLX frustration subscales. Consequently, TLX measures of mental demand and effort did not vary included.

A closer examination of the impact of time limit on performance using paired comparisons and a Wilcoxon Signed Ranks Test found that the performance achieved with the different time limits were statistically different between the 8 and 13minute ( $Z = -2.336$ ,  $p = 0.019$ ) and the 8 and 18 minute ( $Z = -1.969$ ,  $p = 0.049$ ) pairs. In other words, instead of a linear trend of increasing performance with increased time limit, performance at the 8-minute mark was lower than with the other time limits. This result is similar to those found by Johnson, Kuchar and Oman (2002).

A correlational analysis found that performance and time limits were marginally correlated ( $r = -0.180$ ,  $p = 0.083$ ). A partial correlation which controlled for the effect of CCM revealed a decrease in the correlation between performance and time limits and a loss of significance. Thus, the impact of time limit on performance can not be significantly explained without including CCM.

However, the relationship between CCM and performance, as shown in Figure 2, is non-linear. A Kruskal-Wallis test across all CCM levels revealed a marginally significant difference between the CCM levels  $\chi^2(3) = 7.014$ ,  $p = 0.071$ . Paired comparisons were also conducted using a Mann-Whitney test and revealed a significant difference in performance between the scrambled and strategic modes ( $Z = -2.133$ ,  $p = 0.023$ ) and the scrambled and opportunistic modes ( $Z = -2.15$ ,  $p = 0.033$ ). This high performance with the opportunistic CCM questions the notion that "higher" CCMs (tactical and strategic) necessarily correspond to improved performance.



**Figure 2:** Median Performance and Time Limits by Self-Assessed Contextual Control Mode

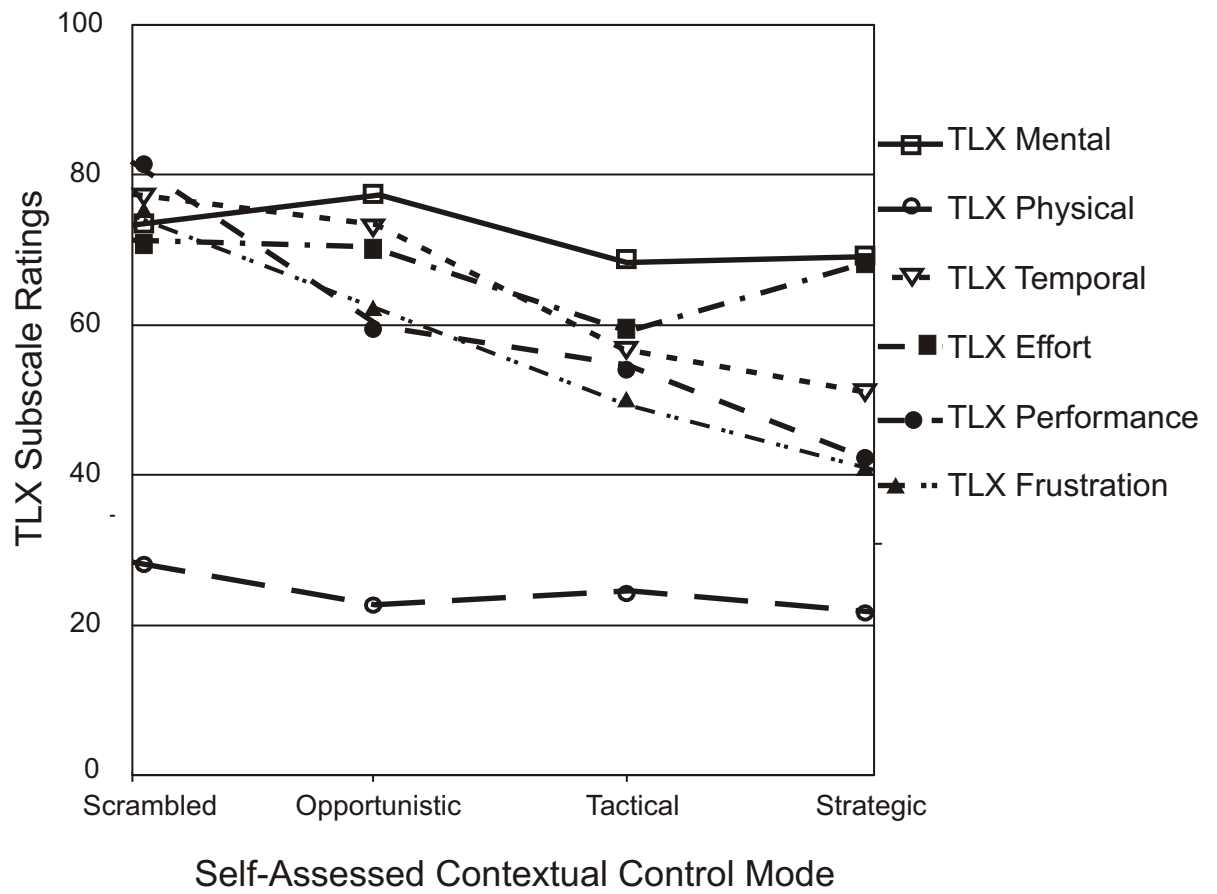
Figure 2 illustrates performance as a function of both CCM and time limit. Although the form of the data and the low number of observations in some of the conditions prevent a statistical comparison, it is interesting to note that, in two of the four time limits, participants who assessed their CCM as opportunistic had the same or better levels of performance than those in a strategic mode. Additionally it is interesting to note the drop in performance across all CCMs in the 8-minute time limit condition.

A Kruskal-Wallis test revealed no significant effect of time limits on the number or direction of transitions between CCMs. However, participants reported transitioning between CCMs in 55% of all runs in the first part of the experiment, a high percentage given the lack of changes in task demands and the explicit representation of time limit. This may be an artifact of the relative novelty of this task to the participants.

The second objective of this experiment was to compare externally observable measures with self-assessed CCM. We calculated the partial correlation between the observable measures of information seeking (PEUI and FDRI) and the CCM while holding time limit constant, as time limit is correlated with both the percentage of external information ( $r_b = 0.578$ ,  $p < 0.001$ ) and FDRI ( $r_b = 0.440$ ,  $p < 0.001$ ). The partial correlation indicated that neither the PEUI ( $r = -0.188$ ,  $p = 0.071$ ) nor FDRI ( $r = -0.164$ ,  $p = 0.102$ ) were significantly correlated to CCM, although the FDRI did decrease as the self-assessed CCM moved towards strategic, mirroring greater time taken for other activities between information requests.

Additionally, the self-assessments of CCM and workload were compared (Figure 3). A partial correlation analyzed the relationship between the self-assessed CCM and each of the TLX subscales while controlling for the effect of time limit. Three TLX subscales correlated significantly to the CCM: temporal ( $r = 0.231$ ,  $p = 0.037$ ), performance ( $r = 0.349$ ,  $p = 0.003$ ), and frustration ( $r = 0.506$ ,  $p < 0.001$ ). Notably, none of the TLX assessments of demand or effort correlated with CCM.





**Figure 3:** TLX Subscale Scores by Self-Assessed Contextual Control Mode

### 3.3.2 Experiment Part 2: Sudden Increase in Task Demand

The second portion of the experiment examined the association between increased task demands caused by an unexpected disruption and performance. A Sign Test found no statistically significant differences in performance between the original runs and those with increased task demands.

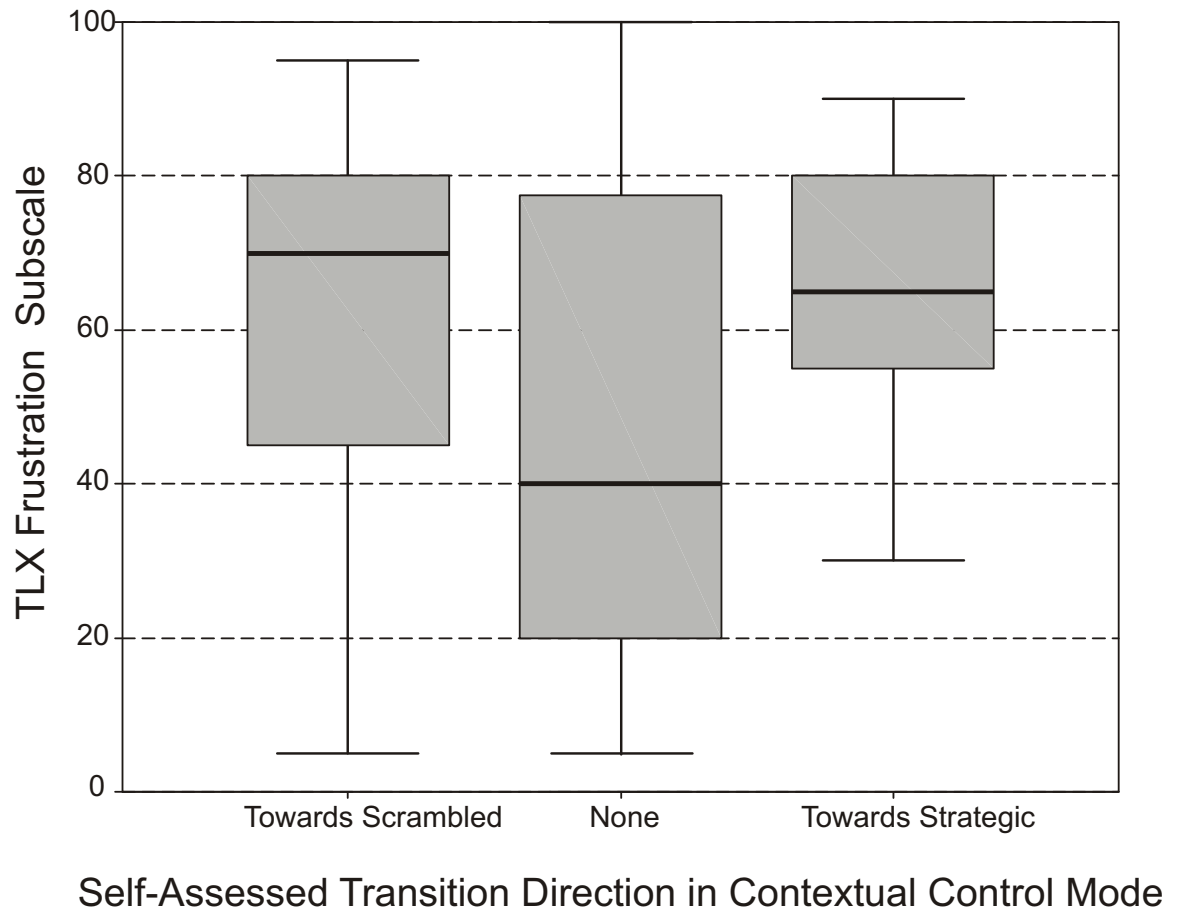
Comparing the results found in the disrupted condition with its undisrupted counterpart conducted in the first part of the experiment, a Wilcoxon signed ranks test revealed that three of the workload subscales indicated significantly higher workload in the presence of increased task demand: TLX mental ( $Z = -2.54$ ,  $p = 0.011$ ), TLX temporal ( $Z = -2.63$ ,  $p = 0.008$ ), and TLX frustration ( $Z = -2.89$ ,  $p = 0.004$ ). Self-assessed CCM was not significantly affected by increased task demand. Likewise, a Sign Test found no significant difference in either the number of CCM transitions or their direction between runs which included increased task demand and runs that did not.

Finally, we examined transitions between CCMs for their impact on the TLX workload subscales, CCM and performance, using a Kruskal-Wallis test. The only two measures found to be significantly impacted by CCM transition were the TLX frustration subscale  $\chi^2(2) = 7.008$ ,  $p = 0.030$ , as seen in Figure 4, and the self-assessed CCM  $\chi^2(2) = 10.334$ ,  $p = 0.006$ . Participants reported lower frustration and higher (closer to strategic) CCM when they did not transition.

## 3.4 Discussion

### 3.4.1 Time Limit

These results contradict both resource and subjective utility theories, as we found no linear effect of time limit on performance, and consequently join a growing body of evidence against these theories [12, 48, 69, 101]. The findings in this study are remarkably similar to those of Johnson, Kuchar, and Oman (2002), who found non-linear changes in performance in response to time limits. The results of this study show that, even with the inclusion of CCM, the correlation between performance and time limit was only marginally significant. This may have been an artifact of the participants' lack of expertise or, as it mirrors findings



**Figure 4:** Boxplot of TLX-Frustration scores by Self-Assessed Contextual Control Mode

from other studies with experts, it may not. Rather than viewing an operator’s workload as some ratio of task demand to time available and performance as the inverse of such a ratio, participants reported modifying the manner in which they approached their task. Sometimes these modifications maintained a high level of performance in the face of time limits, such as the high performance often associated with the opportunistic mode. In other cases these modes may have been ineffective, a possible explanation for the performance with an 8-minute time limit being lower, on average than with a 3 minute time limit.

Embedded within COCOM are two assumptions. The first is that the CCM used by an individual will be highly correlated to the subjective perceptions of available time (Hollnagel, 1993). The data presented in this study does indeed corroborate this hypothesis as a general but not ubiquitous rule. The second assumption states that a ”higher” or more strategic CCM should generally correspond to higher performance [1]. However, there does not seem to be a clear CCM which had the best performance across all time limits. We instead expected selection of the CCM appropriate for the resources available (including time limit) would correspond to the best performance within each time limit. For example, when time limit did not support a strategic CCM, we expected better performance with CCMs which provided a coherent pattern of activity within the time limit given. Some combinations of CCM and time limit provided higher performance, such as opportunistic CCM with the 13-minute time limit. Unfortunately, the sample size in this experiment can neither confirm nor deny our expectation. The results indicate that a wide variety of CCMs are used with varying degrees of success. These successes include the high performance associated with the opportunistic mode, similar to discussions of NDM that illustrate high performance with the RPD-type of decision making behavior that we associate here with the opportunistic mode.

### **3.4.2 Contextual Control Mode Assessment**

The self-assessed CCM scale, developed for this experiment, was found to be useful. Participants reported no trouble using the instrument, and the results correlated with the TLX subscales for temporal, performance, and frustration. While the results are based

only on subjective assessments of CCM, frustration, and performance, do demonstrate that participants perceived their behaviors to be more closely related to performance (and to frustration, defined in the TLX description as satisfaction with your performance) than to measures of load and effort, indicating that CCM measures different aspects of cognitive demand than demand and effort. However, this self-assessment instrument warrants further validation and "remains susceptible to all of the limitations of any self-assessed psychometric such as construct validity and the participants' ability and willingness to accurately self-assess" [99].

### **3.4.3 Contextual Control Mode Transitions**

The unanticipated increase in task demand introduced in the last run of this experiment had much less of an impact than anticipated. It was only found to significantly affect the TLX subscales for mental, temporal and frustration workload. Increased task demand had no observable effect on the CCM, transitions between the CCMs, or performance. If, however, one considers the high percentage of CCM transitions both with and without the increased task demand, transitions between CCMs may be common, rather than primarily caused by abrupt increases in task demand as generally believed. Alternately, the use of novice participants may have prompted more transitions than normal. Further, the magnitude of the increase in task demand may not have been sufficient to induce transitions. Transitions did, however, correlate significantly with participants' self-assessed CCM, and the frustration that they felt. Interestingly, transitions in either direction appeared to be detrimental.

## **3.5 Motivation**

The results from the preliminary experiment were encouraging in that they showed no link between time limit and performance and showed linkages between CCMs and levels of temporal workload, performance and frustration.

The results, however, leave a number of questions yet unanswered. The most obvious is the role in expertise in number, direction and affect of CCM transitions and CCM modes used. Additionally, the question of how to best support individuals operating in different

CCMs is still unanswered. The remainder of this thesis addresses these questions.

## CHAPTER IV

### UNDERSTANDING AND VISUALIZING THE WORK

At this time the role of both pilots and air traffic controllers has been well documented [7, 10, 20, 32, 63, 72]. Less, however, has been written about airline operations [84, 90]. Optimization software packages have been designed and implemented to aid Airline Operations Managers (AOMs) at schedule recovery. However, these tools have been developed without proper consideration for the AOM's work. As a result they are rarely used, as they are often inappropriate for routine tasks. Further, when the tools are used, disuse and lack of understanding of the tools often cause AOMs to disregard their suggestions.

This chapter examines the work of AOMs in the context of the larger work of an airline operations control center (OCC) at four US airlines of varying sizes. The airlines included in this analysis range in size from 50 to 700 aircraft and 160 to 2500 flights per day. The use of Contextual Inquiry examined the human's work, their use of available tools and their interaction with everyone actively dependent upon their work. Contextual Inquiry provides a broad scope and a unique emphasis on examining the work through five distinct lenses: information flow, artifact use, cultural influences, physical affordances and constraints, and task analysis.

The chapter begins with an overview of airline operations and then explains the contextual inquiry process and the creation of work models. Next it discusses the AOM's primary goals, tasks and their primary sources of information. The chapter continues with a detailed discussion of the work models created from the contextual inquiries. These insights provide the basis for work redesign of and the the CWSS design discussed in subsequent chapters.

#### *4.1 Contextual Inquiry of Airline Operational Managers*

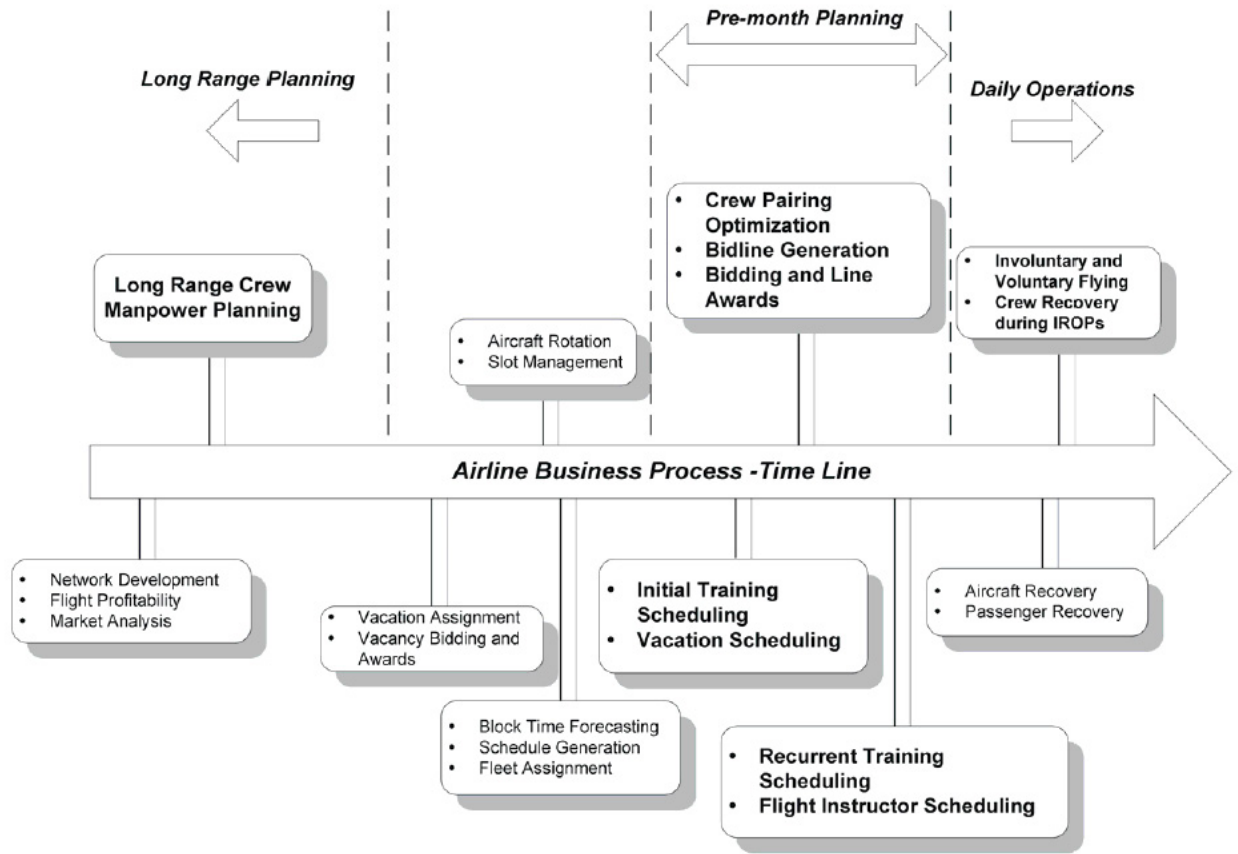
A set of contextual inquiries was conducted at four US airlines over the course of two years (2004-2006) for a total of over 150 hours of direct observation. A range of ethnographic

methods could be used to guide the conduct of these observations and to gather the information necessary to create these models. I selected a structured version of ethnography called Contextual Inquiry [2,45]. Contextual inquiry allows an examination of how a system operates while taking into account not only the users but also others in the organization dependent upon the work. It is centered on four guiding principles: context, partnership, interpretation, and focus. The first principle, context, implies that the interview must take place where the work is being conducted. Interviewing in context allows the interviewee's actions and their answers to questions to be more accurate by being situated. The second principle, partnership, requires that the common role of interviewer-interviewee is replaced with the role of mentor-mentee, enabling the interviewee to take more control in the interview and thus impart the knowledge that they feel is important instead of simply answering questions. The third principle, interpretation, signifies that a shared understanding must be developed between mentor and mentee. To accomplish this, the interviewer must not only abstract and describe their observations, but also share these interpretations with the interviewee for refinement and correction. The fourth principle of focus implies that, unlike pure observation, contextual inquiry allows the interviewer to steer the conversation gently to remain on task, while also capitalizing on unexpected insights.

#### **4.1.1 Task Characterization**

Presently, there are four distinct phases in an Airline Business Time Line. The first phase, takes place between 1-5 years prior to flight and includes long-range planning, marketing analysis and profitability studies for new and existing routes, and long range crew and manpower planning. The second phase occurs 3-9 months out and consists of schedule generation, fleet assignment and crew assignment bidding and awarding. The third phase, called the pre-month planning, occurs 1-1.5 months prior to flight and consists of pairing crews with flights, initial training scheduling and flight instructor scheduling. The final phase, called daily operations, occurs the day of the flight and includes crew, aircraft and passenger recovery due to irregular operations [91]. Recovery refers to the reassignment of crews and passengers to flights and flights to aircraft. These business phases are illustrated





**Figure 5:** Airline Business Time Line

graphically in Figure 5. This thesis is primarily concerned with the Daily Operations phase of the airline business schedule.

To better organize daily operations most major air carriers have created operational control centers including all of the personnel involved. These personnel include aircraft dispatchers, meteorologists, pilot representatives, flight crew representatives, maintenance personnel, customer service representatives, security, revenue management, freight, fleet managers and airline operations managers. Co-locating key representatives from all important breaks down the normal “stove piping” that happens within disciplines so that problems can be more quickly addressed. Airline operations managers serve as the primary individual tasked with ensuring the cooperation of all parties involved.

The primary task of an Airline Operational Manager (AOM) is to maintain the airline's published schedule to the extent possible given current external conditions. Normally external conditions include predicted weather related difficulties and air traffic control restrictions, but can also include random issues like inoperable equipment at airports and maintenance failures on aircraft. The AOMs maintain the flight schedule by making decisions about how to cope with deviations. Often these decisions are non-time-critical with a look-ahead between 30 minutes to 6 hours. However, some decisions are very time critical such as the rescheduling of flights after an emergency shut-down of a runway or the unanticipated depletion of fuel or de-icing fluid at an airport.

AOMs are experts, often having risen through the ranks at an airline over several years. Correspondingly, they know all aspects of the airline industry. They understand what it is like for a crew to be stuck somewhere, or for a gate agent to deal with angry customers after a flight has been canceled. AOMs spend a lot of time developing and maintaining interpersonal relationships, and as such verbal communication is very important to the work culture. AOMs can be deeply suspicious of upper management and management in general. They are highly loyal and truly wish to see their airline be the best airline. AOMs do not work in isolation, but function as part of a larger operations team in which they often play the coordinating role. AOMs observed in this study were organized into three daily shifts. Often AOMs' responsibilities are geographically separated, e.g. different sectors of the country: Eastern, Central, Western, International, Main Hub and ATC Liaison. In some airlines an additional AOM serves as an interface between ATC and the airline.

Schedule adherence is a high-level task that requires the AOM to perform many activities including communication and co-ordination, planning, judgment, decision making, information searching, execution of decisions, representation of data for memory retrieval and data abstraction. Using Vicente's (1999) complexity classification system, this task can be described as having [97]:

**A large problem space:** the set of all possible actions for each flight scheduled;

**Distributed:** many pieces of information must be requested from other personnel, such as

the maintenance department’s estimate of a repair time and an aircraft dispatcher’s estimate of an aircraft’s arrival;

**Dynamic:** decisions made at one time can ripple throughout the day. For example, one aircraft arriving late on a morning flight may delay all of the flights subsequently scheduled for it and, if other flights are also delayed to allow passengers to make their connections, one delay in the morning can quickly ripple throughout an entire airline’s schedule for the rest of the day;

**Hazardous:** poor choices made by airline managers can result in extreme economic consequences for the airline;

**Highly coupled:** aircraft availability must be matched with crew schedules; and

**Highly mediated:** the airline manager cannot directly observe the airline schedule by watching the aircraft land and depart, and must therefore depend on multiple computer interfaces to gather the information required.

In addition to the AOMs’ environment being complex, it also requires the use of dynamic decision making as defined by Brehmer and Kershtolt [4,58]. Disturbances are the impetus of the schedule adherence task. Further, the real world adherence task is also social, with multiple managers each representing the needs and constraints of many divisions within the airline. As in many complex, dynamic domains, decisions must often be made quickly, yet information may be uncertain or difficult to obtain. Other information must be retrieved from cumbersome text-based interfaces presenting data about hundreds of flights. In our own observations we have found that managers’ approaches to this task can vary widely. On a day with few disruptions, the manager may research a great deal of information; consider many possible alternatives to minimize flight delays, and co-ordinate with many other personnel. On a busy travel day with major disruptions the manager may resort to broad-brush measures, such as significantly delaying flights and operating the entire fleet an hour behind schedule.

### **4.1.2 Sources of Information**

The information required by the AOMs is readily available through a variety of (sometimes redundant) sources. The primary source of information is a text-based interface into the primary scheduling computer system. This computer system contains data about aircraft and crew schedules as well as weather information, notices to airmen (NOTAMS), information about the facilities at all of the airline's serviced airports, and the current duty roster of all operations staff. The AOMs are highly skilled at using this system to find the information they require, and they are often only one text command away from their intended information. AOMs are also aware of what information cannot be found in the computer system and are adept at finding the required information from the correct person. The one aspect that slowed down the AOMs observed for this project was a high number of typographical errors made while entering commands into the system. As some of these commands were upwards of 20-30 characters in length, these errors were understandable.

### **4.1.3 Objectives**

Often AOMs must weigh competing objectives when deciding which solution to implement for a given problem. For example, the choice between canceling and delaying an aircraft may involve the difference between quickly canceling a flight (which may cost the airline less money due to less network disruption), but delaying the aircraft may prove to be better from a customer satisfaction point of view. Such trade-offs are left up to the judgment of the AOM. The AOM may be provided with a list of valuable flights, i.e., those not to be canceled if at all possible; these flights may be high-revenue flights or may simply be carrying a VIP. Other than this information, AOMs are given no explicit guidance, as to the relative importance of multiple competing objectives.

### **4.1.4 Changes Underway**

The introduction of operations research methods and powerful computers are changing the current model of airline operations in two fundamental ways. First, the distinct phases of airline operations illustrated in Figure 5 have begun to amalgamate. The introduction of

more powerful computers and more advanced mathematical algorithms allow once enormous problems such as establishing an optimized schedule to be completed in a fraction of the time once needed. This has in turn allowed the an schedule to be optimized later in the process.

Second, more automation and more sophisticated automation is being introduced into airline operations control centers. This automation provides AOMs unprecedented access to information – information that they are accountable for. AOMs will be under greater pressure than ever to reduce the disturbance caused by off-nominal operations and to return to the published schedule as quickly as possible.

## **4.2 Work Models**

The data collected during the contextual inquiry is incorporated in this section into a series of work models to describe at the role of an AOM from a variety of angles. The five distinct model types presented here include a flow model to examine information flow, a physical model to examine the physical context, artifact models to illustrate sources and stores of information used by AOMs, a cultural model to illustrate cultural forces and pressures which impact the work of AOMs, and sequence models to examine the procedures and motivations behind some of the AOMs' actions and decisions. These work models illustrate 1) the usefulness of analyzing human behavior and cognition at a work-level abstraction and 2) the variation in work practice as a response to contextual (including, but not limited to the physical ecology) changes. The set of models described by the Contextual Design [2] process facilitates modeling organizational and cultural aspects of work practice which are not captured well in other modeling paradigms such as cognitive work analysis.

### **4.2.1 Information Flow Models**

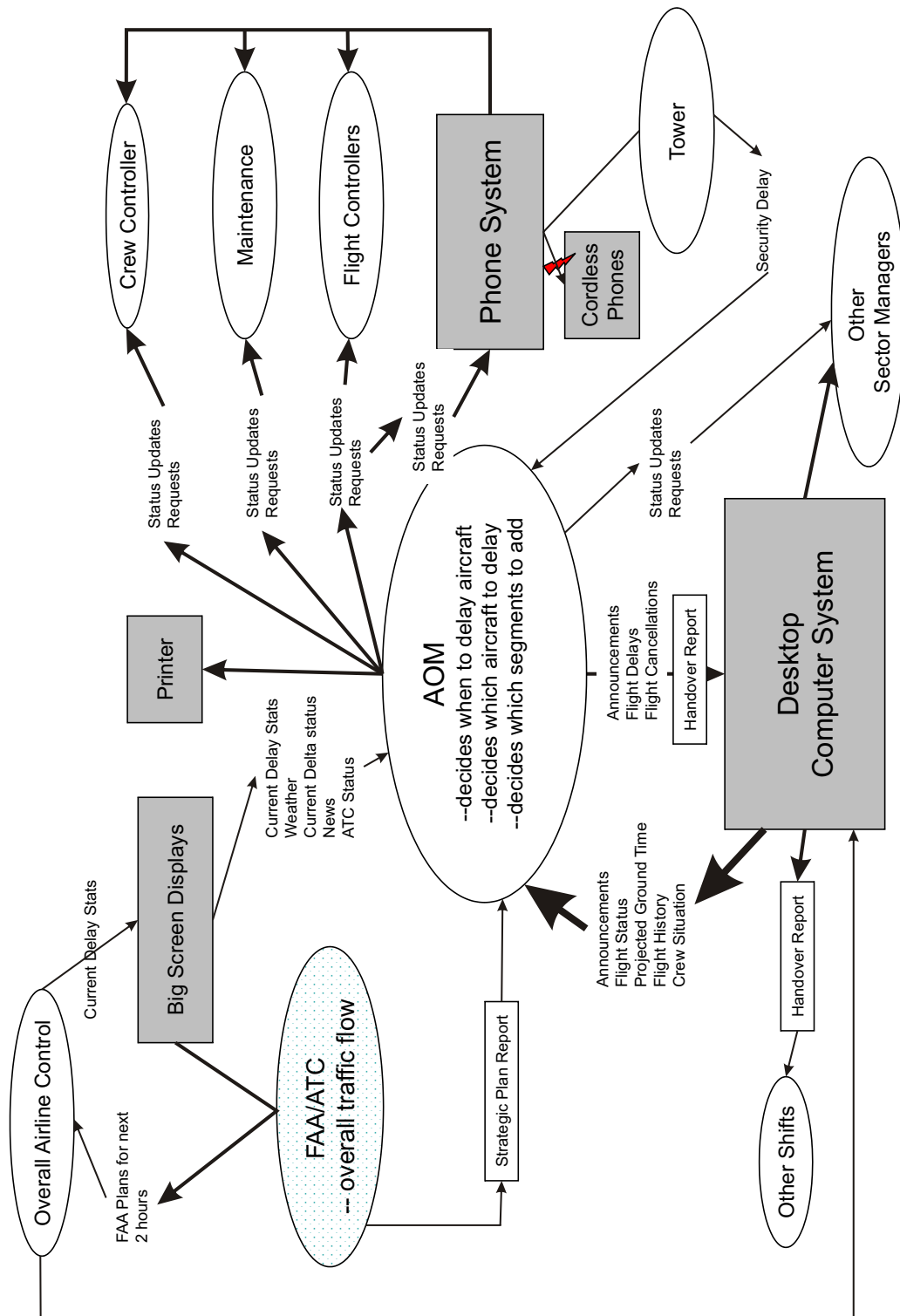
The purpose of a flow model is to show the flow of information between individuals and artifacts within the system and to note any breakdowns in information flow. The flow model for the AOMs involves both individuals and computer systems. Individuals are represented by ovals. Artifacts (tangible pieces of information) are represented by small rectangular boxes, and areas of information storage are represented by shaded boxes. The flow of

information between these elements is illustrated by arrows. Breakdowns in information flow are represented by lightning bolts. The information flow models for the four airlines are shown in Figures 6 - 9.

The smaller three airlines all have similar information flows as the AOMs rely heavily on computer systems. Most of the information collected by the AOMs comes through computer systems and most of the information coming from the AOMs is disseminated through the computer systems. The computer systems in all three airlines are supplemented by the phone systems. Additionally, the two smallest airlines commonly use email for information collection and dissemination. One of the main differentiating aspects of the largest airline is the use of dot matrix printers as a primary source source of information and work. The majority of the material printed by the printers is not actually requested by the AOMs, but is instead information in the form of alerts, routing changes, landing slot assignments, etc., sent to the printer via electronic message from various sources in the airline. Consequently, on busy days the printer is almost constantly printing and just sorting through the printouts and keeping the paper contained can take a large amount of their time. The printers also make a great deal of noise, leading one AOM to comment that an outside observer could easily tell how busy the day was by how loud the OCC was.

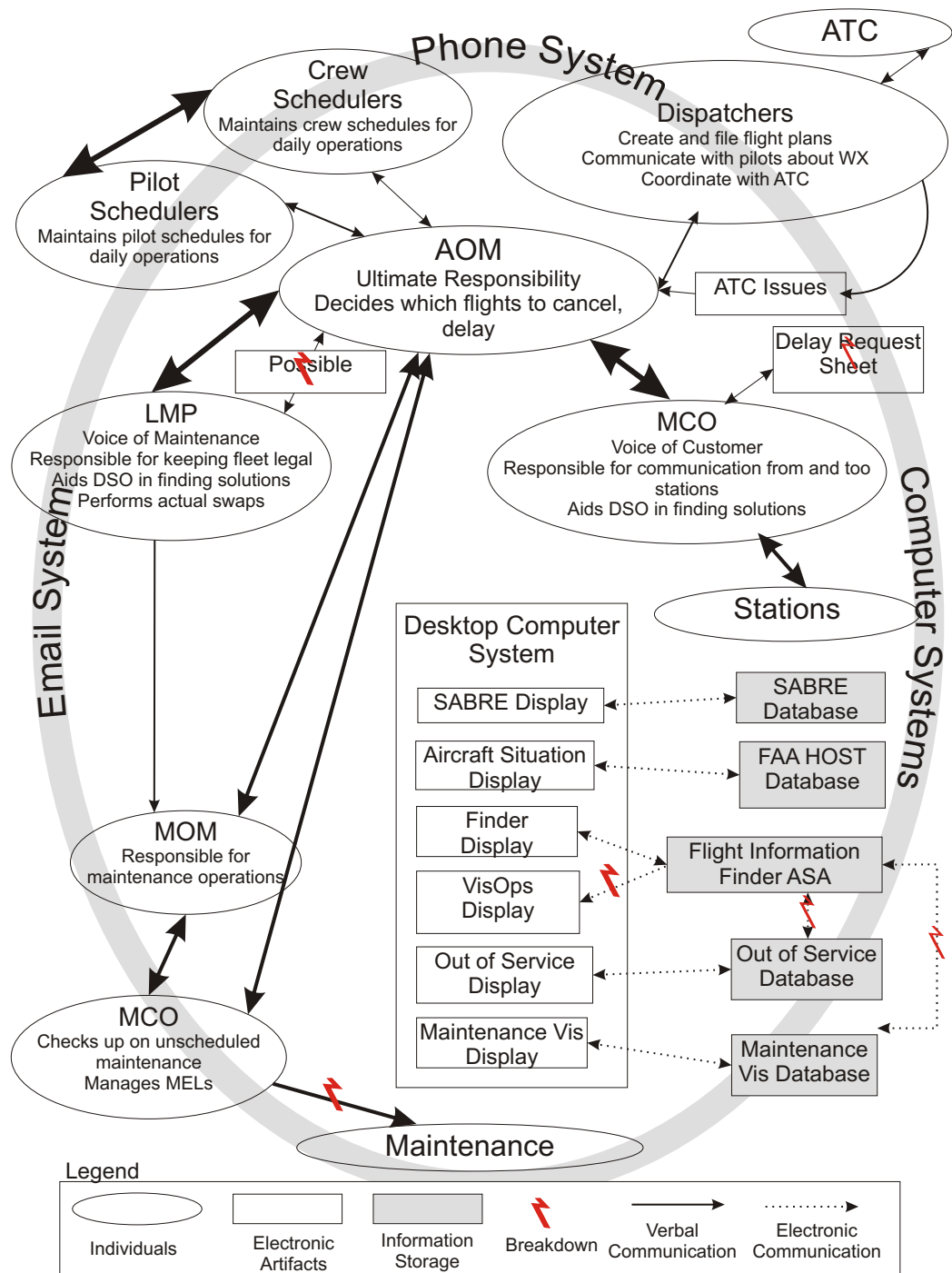
In smaller airlines the AOM is depicted at the center of the information flow models, as most information and decisions pass through them. In the largest airline, there are two centers of activity, the AOMs and the ATC Coordinators (ATCCs). The ATCCs work on ground delay programs and leave all other schedule issues to the AOMs. This model captures how, at this airline, the ATC coordinators (ATCCs) do not actively coordinate directly with the AOMs. Instead, they formulate plans which are best overall for the airline and send them to the printers throughout the airline via electronic alerts and schedule changes which automatically print out. The ATCCs communicate regularly with the Air Traffic Control System Command Center (ATCSCC) in Herndon, VA during both the regularly scheduled teleconference and the ad hoc teleconferences. A common complaint heard from the ATCCs is that the scheduled teleconferences aren't really conferences at all, but are instead statements of intent. Instead, most of the actual negotiating happens



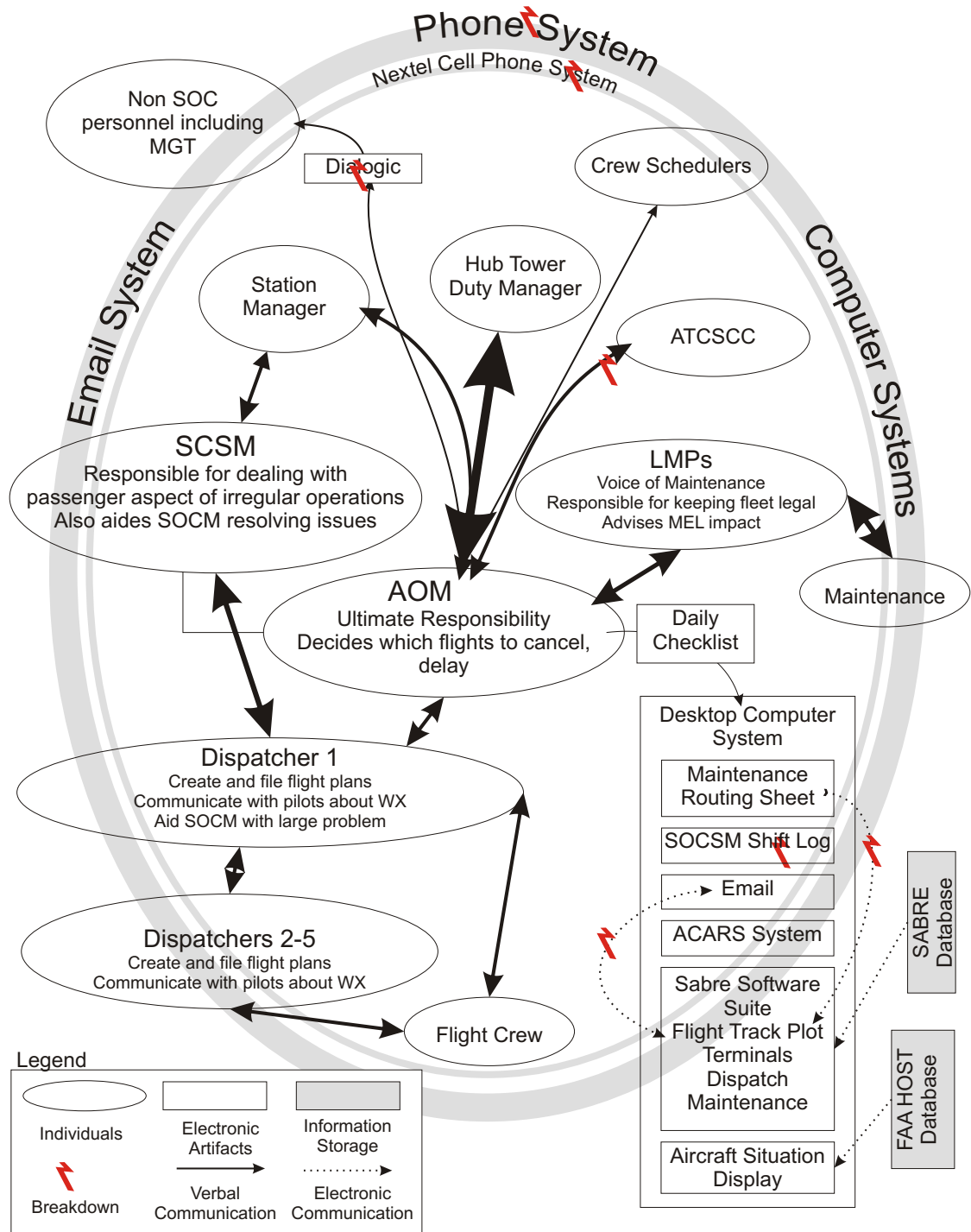


**Figure 7:** Information Flow Model – 500 Aircraft Airline





**Figure 8:** Information Flow Model – 100 Aircraft Airline



**Figure 9:** Information Flow Model – 50 Aircraft Airline

during the ad hoc teleconferences, reducing the benefit, from an ATCC perspective, of the scheduled teleconferences.

As the AOMs work in teams, the information flow models also contain a large number of other individuals. While no consistent hierarchy exists between the individuals shown on the models, in general the AOM has ultimate responsibility for the airline's operations. It is up to the AOM how much coordination he wishes to do. Often it will vary by context. For example, in cases with low workload, the AOM often spends a significant amount of time coordinating with other airline employees. With a high level of coordination, often the AOM will allow his colleagues to suggest possible solutions. Conversely in situations of high workload, the AOM coordinates only minimally with his colleagues, relying instead upon his own experience. This variation is discussed more thoroughly in the following section.

The flow models clearly show the large number of, often redundant, information sources. These sources include computer systems as well as other airline employees such as customer service officers, maintenance planners, and crew schedulers. In the smaller airlines the two primary sources of information were the schedule visualization software which displays the airline's schedule as a Gantt chart with each row representing a separate aircraft and each flight represented by a colored rectangle, and the text-based terminal with access to the airline's primary schedule database. In the larger airlines the primary information source is the text-based terminal. To access the information needed for each decision often multiple information requests must be made to either the computer or a colleague (who may have access to additional computer systems better suited to retrieve information or assess potential solutions). Any information accessed must either be memorized, transcribed onto a note pad or left on the screen for future access. Consequently the AOM spends much of her time accessing information required and adjusting decisions or plans based on the most recent information available. For example a problem with a flight which will likely delay a flight by 30 minutes might first cause the AOM to look up the aircraft of the current flight. Then the AOM might look up the flight schedule for that aircraft. If the follow-on flight after the affected has sufficient time on the ground to absorb the delay the no further action might need to be taken. However, if the time on the ground is not sufficient then

the AOM will need to begin to look for possible aircraft at either the current location or the destination with which a swap might be made. The AOM might further also need to look up the schedule for the flight and cabin crew to determine the delay's affect on their schedules.

Several potential breakdowns were identified in the models. In one case, although the AOMs are provided with a cordless phone so that they may be mobile while using their phones, in reality, many do not use them. They prefer instead just to tell another AOM where they are going. In this way AOMs attempt to cover for one another, however in reality most of the calls are simply logged by the covering AOM as they are unable to look up any information on a problem that the missing AOM is working on. Another breakdown which was common across multiple airlines was a disconnect between maintenance and the AOMs over which aircraft are actually available and which ones are undergoing maintenance. Maintenance personnel often take advantage of open aircraft to perform routine maintenance without marking the aircraft as out of service (as maintenance is then officially "charged" for that aircraft's time). This practice often leads to AOMs requesting the use of an aircraft which is not available. Additionally, many breakdowns were caused by inefficient use of information flow; AOMs to commonly cut and paste information (often in the form of text) from one computer system into another computer system either to log it or to disseminate it.

#### *Contextual Control Modes*

Figures 6 - 9 provide a consolidated information flow model for each airline in their most common form the contextual inquiry. However, representing the 'common behavior' cannot illustrate how the information flow varied by context, including the number of concurrent schedule disruptions, the state of the overall airspace, the number of resources (aircraft and crews) available, the impact of the schedule disruptions and the amount of time available to address each disruption. Figure 6 - 9 showed the information flow during the Tactical mode, which is the mode that AOMs spend the majority of their time. Figure 10 shows

how the information flow changes in one airline as the AOMs transition to either the Opportunistic mode or to the Strategic mode. In the Opportunistic mode AOMs minimized the information flow by concentrating on getting as much information from their computer system and the printers instead of coordinating with the Crew Schedulers, the Ramp Managers or even Maintenance Operation Control. Transitioning in the opposite direction to the strategic mode, the AOMs focused on the use of a decision support tool to aid them in making optimal decisions. They still coordinated with their colleagues, but in a less direct manner, using their computer systems to asynchronously coordinate.

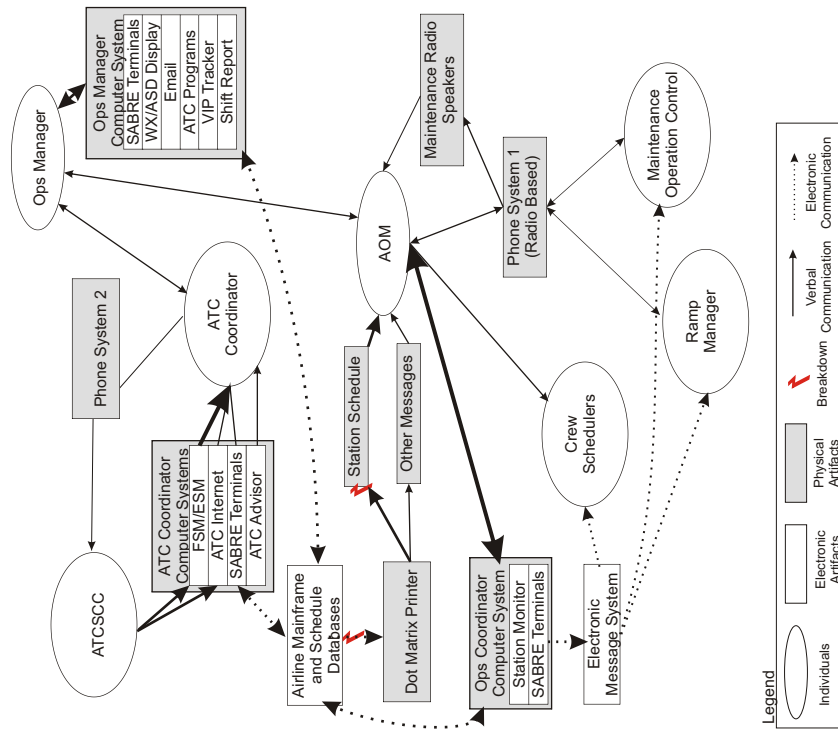
#### **4.2.2 Artifact Models**

The artifact models identify how artifacts help or hinder work. AOMs use a variety of aids to help them with their work; however, few of them are physically tangible. The two physical artifacts are their workstations and their computer screens, see Figures 11 and 13. Workstations are organized such that the AOM has a computer display consisting of two or three 15-17 inch computer monitors interconnected to display a single computer desktop. This large computer display area enables AOMs to simultaneously view many of their software tools, such as radar tracks, weather radar and DOS-based text interface windows. Each workstation is also connected to a printer, which enables AOMs to print out any information displayed on the computer terminal. Depending upon the airline and the physical arrangement, the printer may be integrated into the workstation or may be shared between multiple workstations. In addition, each work station is equipped with a telephone system, a keyboard and a mouse. The two larger airlines have phone systems with dedicated touch-screen interfaces, while the smaller two airlines have standard multi-line office phone systems. The two larger airlines' phone systems are integrated into the airline's radio communication network.

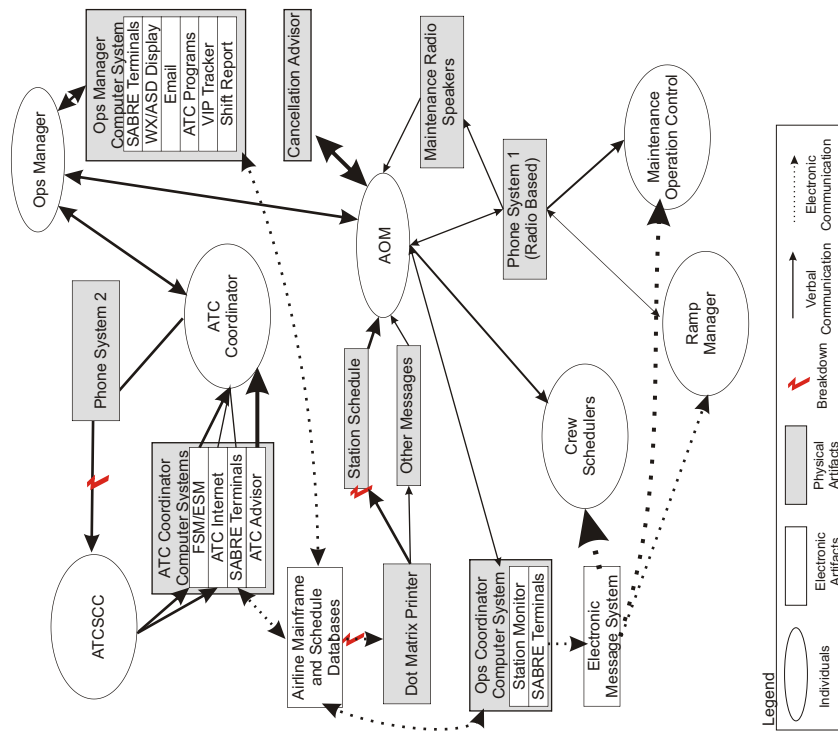
At the largest airline, one vital artifact was a computer print out of the entire day's schedule for a given hub. A truncated example of the print outs can be seen in Figure 14<sup>1</sup>. Actual print outs vary in length, and can be several feet long. This allows the OCs to scan

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<sup>1</sup>Several columns in the printout have been blurred to obscure data that would reveal the airline's identity.

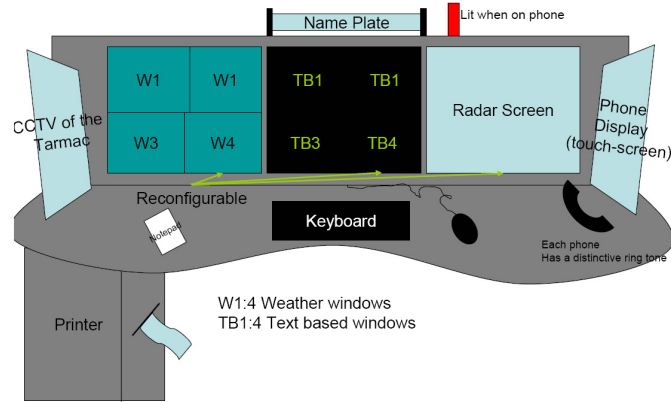


(a) Opportunistic



(b) Strategic

**Figure 10: Information Flow Model – 700 Aircraft Airline**  
60

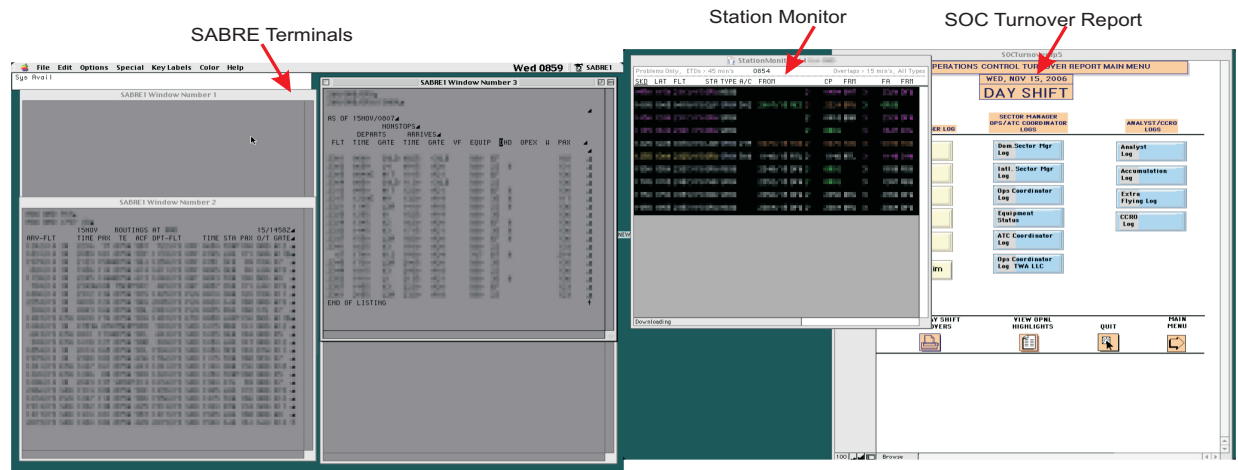


**Figure 11:** Artifact Model - Desk

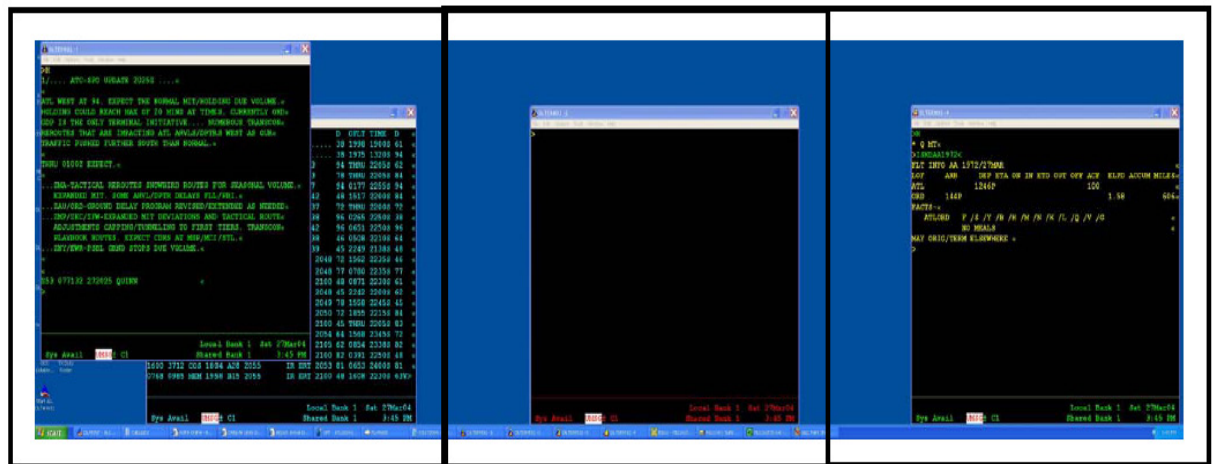
for possible equipment swaps and annotate the schedule. Depending on the day, the number of schedule printouts required, and the degree to which they are marked up varies. The printouts work well; however, they have the drawback that they are obsolete the moment they are printed, as the schedule continuously evolves. Additionally, the printouts are limited in the amount of information they can hold by the width, that can be printed. For example, while the printer paper is 8.5 inches wide, the printer can only print 6.125 inches, leaving a blank space of over an inch in addition to the necessary margin for dot-matrix paper holes. While the extra space itself provides ample space for the annotations, the OCs would prefer that an additional column of data be printed instead. Much of the OCs time is spent mentally filtering and searching through the printouts for aircraft or flights that meet certain criteria.

The vast majority of the aids used by Airline Operational Managers are software based. These electronic artifacts serve two functions: information presentation and storage. Figures 15-18 illustrate different software programs which present information to the AOMs. Figure 15 shows the primary interface used by the AOMs: a text-based terminal by which the AOMs can interface with the airline's main scheduling database. All four airlines used similar software provided by the same company. For the purposes of this thesis this will be called a schedule terminal. This interface allows AOMs direct access to the scheduling database and is thus extremely powerful. Additionally, each schedule terminal is customized

Tools of choice are based on a now obsolete operating system  
 Dual monitors allow multiple windows to be viewable  
 Dual monitors allow cursor manipulation with a single set of input devices  
 OCs are familiar and competent with the tools at their disposal



(a) 700 Aircraft Airline



2 TERM32

1 TERM32

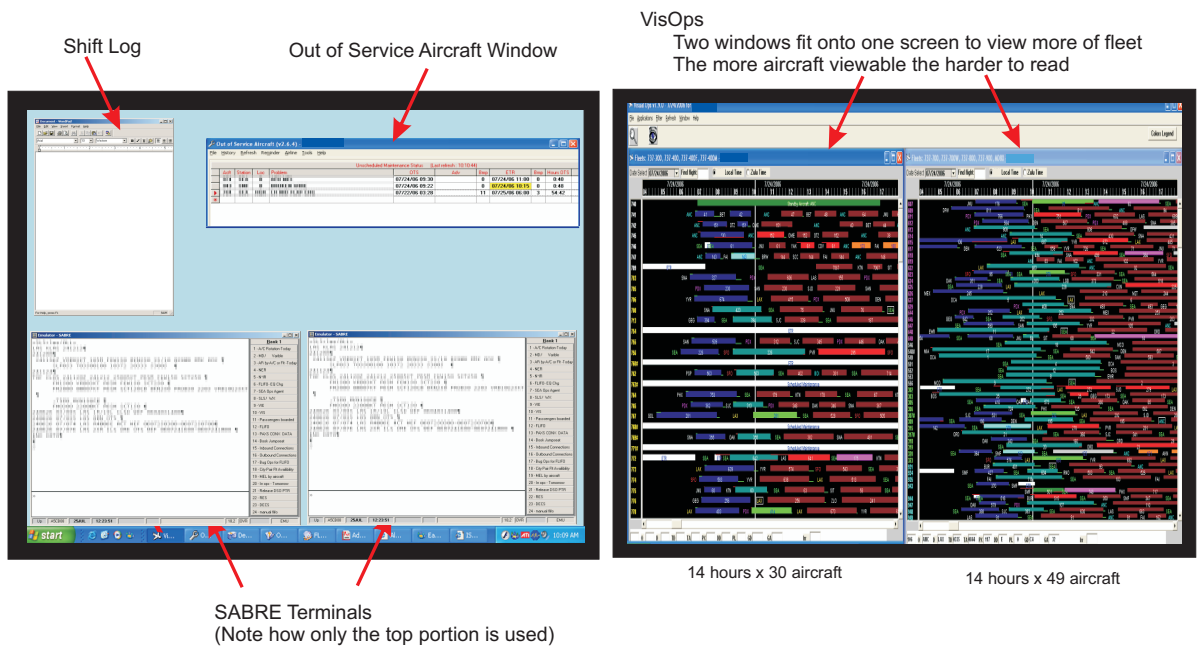
1 TERM32

(b) 500 Aircraft Airline

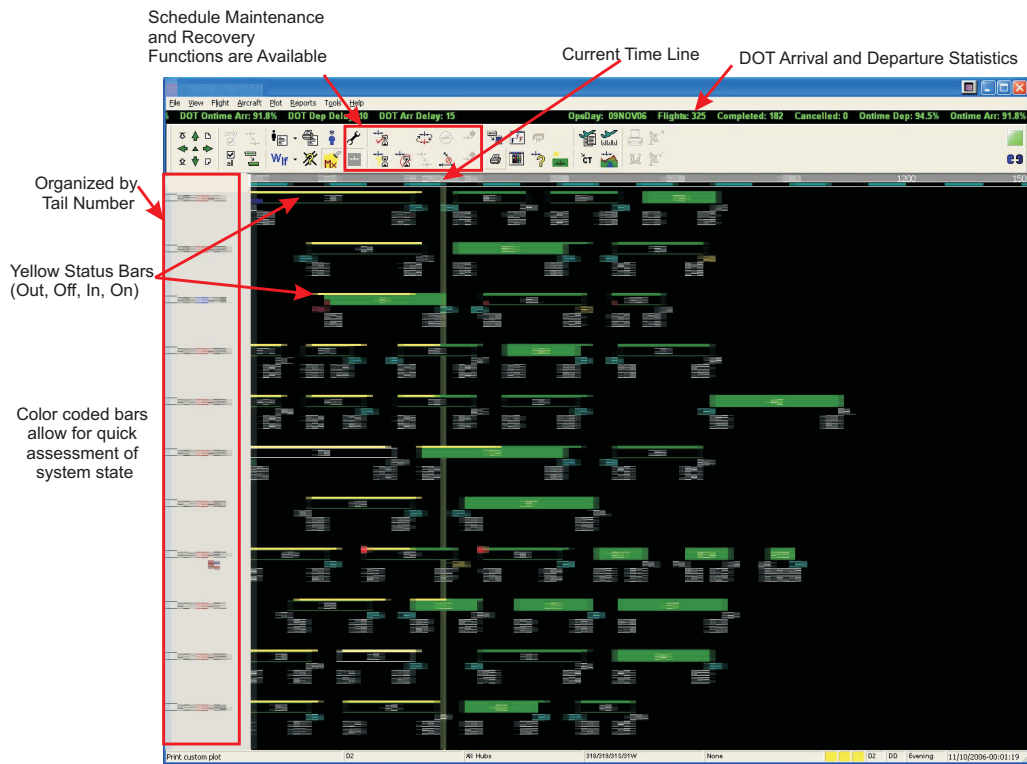
Figure 12: Artifact Models of Computer Stations at Larger Airlines



## DSO Computer Desktop Arrangement



(a) 100 Aircraft Airline



(b) 50 Aircraft Airline

**Figure 13:** Artifact Models of Computer Stations at Smaller Airlines

Much needed but unusable space

Column Headings

Equipment Swaps

ARRV-FLY	TIME	PAX	TE	ACF	OPT-FLY	TIME	STA	PAX	O/T	GATE
IN	2306	143	875W	...	OFF	0719	...	173	...	D36
IN	2314	147	875W	...	OFF	0750	...	176	...	E5
IN	0011	109	875W	...	OFF	0803	...	127	...	A14
IN	0034	83	875W	...	OFF	0806	...	191	...	D49
IN	0614	184	875W	...	OFF	0846	...	169	...	D47
IN	1245	135	875W	...	OFF	1423	...	104	...	A5
IN	1252	170	75ER*	...	OFF	1424	...	141	...	D45
IN	1310	93	875W	...	OFF	1450	...	179	...	D51
IN	1229	164	875W	...	OFF	1453	...	188	...	D34
IN	1354	174	875W	...	PLN	1530	...	188	...	D43
IN	1433	146	875W	...	PLN	1550	...	147	...	A5
IN	1442	159	875W	...	PLN	1600	...	189	...	D48
ETA	1527	189	875W	...	PLN	1610	...	188	...	D34
IN	1435	181	875W	...	PLN	1620	...	170	...	E5
IN	1447	143	875W	...	PLN	1625	...	78	...	D45
ETA	1526	144	875W	...	PLN	1625	...	146	...	A14
IN	1458	175	875W	...	SKD	1705	...	118	...	A7
ETA	1534	174	875W	...	SKD	1710	...	147	...	D33
ETA	1615	177	875W	...	SKD	1740	...	185	...	D43
ETA	1620	170	875W	...	SKD	1800	...	175	...	D47
ETA	1652	163	75ER*	...	SKD	1800	...	172	...	A26
ETA	1645	156	75ER*	...	SKD	1810	...	172	...	D39
ETA	1711	91	875W	...	SKD	1815	...	188	...	E5
ETA	1533	192	875W	...	SKD	1825	...	174	...	D36
ETA	1723	98	875W	...	SKD	1825	...	188	...	A14
ETA	1719	72	875W	...	SKD	1830	...	188	...	D49
ETA	1659	116	875W	...	SKD	1835	...	181	...	D48
ETA	1719	120	875W	...	SKD	1835	...	66	...	C7
SKD	1820	118	875W	...	SKD	1915	...	150	...	E7
SKD	1816	188	875W	...	SKD	1930	...	98	...	D43
SKD	1819	176	875W	...	SKD	1930	...	109	...	A7
SKD	1830	103	875W	...	SKD	1940	...	187	...	D46
SKD	1835	159	875W	...	SKD	2010	...	186	...	D45
SKD	1835	156	875W	...	SKD	2040	...	179	...	D47
PLN	2039	173	875W	...	SKD	2045	...	188	...	D46
SKD	1856	164	875W	...	SKD	2050	...	170	...	D49
SKD	1945	169	75ER*	...	SKD	2050	...	187	...	C7
PLN	1900	151	875W	...	SKD	2100	...	179	...	D34
PLN	2015	174	875W	...	SKD	2140	...	62	...	D43
SKD	2050	129	875W	...	SKD	2145	...	56	...	D47
SKD	2115	88	875W	...	SKD	2220	...	78	...	D51
SKD	2120	114	875W	...	SKD	2320	...	189	...	D42
SKD	2235	170	875W	...	SKD	2350	...	188	...	D44
SKD	2310	139	875W	...	SKD	0705	...	142	...	D47
SKD	1936	161	875W	...	SKD	0735	...	89	...	E7
SKD	2205	96	875W	...	SKD	0745	...	168	...	D33
SKD	2145	159	875W	...	SKD	0825	...	96	...	D34
SKD	2220	180	875W	...	SKD	0835	...	166	...	D49
SKD	2230	57	875W	...	SKD	0905	...	186	...	D43

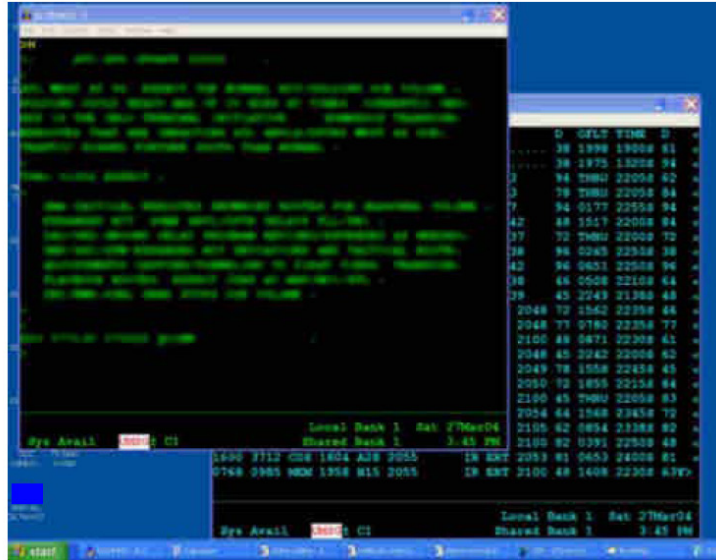
-END- F - DOUBLE PROVISIONED  
M - MINGLETED  
@ - FUEL EFFICIENT AIRCRAFT  
\* - EQUIPMENT CHANGE

Handwritten notes on the right side of the table:

- NSFC
- 059 0400
- 066 0400
- NSFC
- PRSD
- 52U
- 29.0
- 52U
- NSFC
- 56.6 F03

Figure 14: Artifact Model - Schedule Printout

- Old text-based interface
- Primary interface used
- Primary source of information
- Requires memorization of text commands much like Unix or Linux
- Typos are a frequent problem

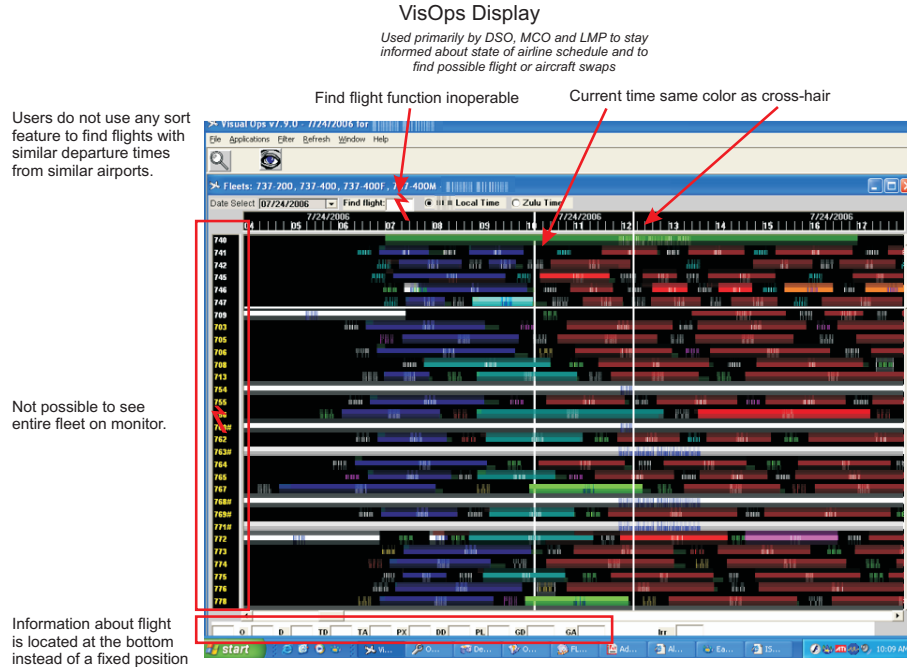


**Figure 15:** Artifact Model - Schedule Terminal

to each airline so that the look, feel and command syntax might vary slightly between airlines.

In addition to the schedule terminal, the two smaller airlines also had software designed to graphically display the schedule, and their AOMs used the two representations of the same data to aid them with different tasks. The schedule visualization tools were used to monitor the schedule for potential deviations, and often to implement schedule changes. Alternatively, the schedule terminals were used to answer specific questions, or to organize information in a way that was not easily accomplished in the schedule visualization tool. The schedule visualization tool is good at highlighting potential problems within the schedule, but, because of the way the schedule is presented, it is difficult to spot problems for aircraft which have “scrolled off” the screen. That is, if the entire schedule cannot be displayed on a single monitor then problems may easily be overlooked as there is no way to filter for aircraft with potential problems.

The larger airlines, lacking a schedule visualization tool, instead use software designed specifically to monitor the schedule for them and to present any potential problems found. Having a program which specifically monitors the schedule for problems and displays them is essential for airlines with a large number of aircraft. The schedule monitors serve as a



**Figure 16:** Artifact Model - Schedule Visualization Tool

form of checklist for the AOMs. Figure 17 shows the two schedule monitors used by the larger airlines.

The schedule monitor for the 700 aircraft airline monitors the airline's schedule for anomalies according to parameters specified by the AOM, including the station of interest, the aircraft type, estimated delay time, estimated turn time, estimated crew arrival time, etc. The problems identified by the Station Monitor are color coded and allow the AOM to quickly identify those issues that an AOM is capable of attending to, versus those which are beyond their control. Unfortunately, once this assessment has been made, there is no good way to sort the list such that issues beyond an AOM's control or needing attention at a later time, can be separated from other impending issues. Once the issue has been resolved, the problem disappears from the Station Monitor. This disappearance can also cause confusion as there is no indication to the AOM (who may have been working on the issue) why or how the issue was resolved. Overall, the AOMs are adept at mentally filtering the list and using it to identify problems, which they then address and coordinate a response.

The schedule monitor used by the 500 aircraft airline monitors the progress of arriving

Color code indicates cause of problem  
Brings problems to OC attention

No good way to organize issues or to mark them as  
1) Having been dealt with  
2) Needing attention at a later time  
3) Ignore because it is out of OC control

Indicates current settings, which can be altered by user

StationMonitor 4.1

Problems Only, ETDs > 45 min's, 0858, Overlaps > 15 min's, All Types

SKD	LAT	FLT	STA	TYPE	A/C	FROM	CP	FRM	FR	FRM
0950	1150	2313/15					2	0484	3	2320
1005	1005	0419/15					2	2324	3	ORIG
1050	1330	2317/15					2	0418	3	2324
1145	1400	2321/15					2	ORIG	3	1637
1225	1225	0370/15					2	0370	3	0370
1255	1300	2325/15					2	1146	3	1148
1550	1550	2337/15					2	ORIG	3	1938
1705	1705	2487/15					2	ORIG	3	1397
1750	1750	0454/15					2	2356	3	2356
1955	1955	2357/15					2	2364	3	2364

Idle Skd 1105 Skd 1158

(a) 700 Aircraft Airline

- List of flights ranked by arrival time
- Serves a a primary cue
- ✗Has 3 views, but only Duty Roster seems to be used
- ✗Weather and NOTAM are provided by other packages

Arrival time:  
Green = early  
Red = late  
Sector managers look out for late flights

Highlighted row will  
bring up history in  
lower pane

Worldpart 58 - 0300Z, Total Flights: 700

File View Duty Roster Help

Duty Roster Weather NOTAM

Flight	Orig	Dpt Time	Dpt	Dest	A	Arr	S	Status	Block	Hold	Prim	Sec	T/O	Dis	Ld
1723A				1922A	-00:35	606	Complete	25000	58					81	BD
1756A				1923A	-00:33	5734	Complete	15800	44					83	DC
1714A				1929A	-00:31	914	Complete	26000	55					64	DB
1717A				1932A	-00:27	691	Complete	26000	45					63	BA
1745A				1934A	-00:26	312	Complete	16800	45					83	DB
1900A				1936A	-00:25	194	Complete							32	CC
1808A				1939A	-00:24	938	Complete	19800	58					62	BD
1817A				1940A	-00:13	1701	Complete	31000	46					75	BA
1757A				1941A	-00:15	921	Complete	20800	53					72	BA
1818A				1946A	-00:11	908	Complete	19000	46					64	BA
1806A				1947A	-00:20	302	Complete	18800	45					83	DA
0852A				1948A	-00:52	1001	Complete							32	AB
1941A				1948A	-00:02	137	Complete	27000	44					48	CC
1801A				1948A	-00:06	372	Complete	18000	48					48	DC
1816A				1949A	-00:18	939	Complete	19800	51					83	DA
1826A				1951A	-00:16	953	Complete	19400	44					46	CA
1816A				1951A	-00:18	962	Complete	20000	50					84	BA
1908A				1953A	00:06	9002	Complete	21600	54					72	BA
1939A				1955A	-00:13	929	Complete	18700	50					84	CA
1747A				1956A	00:02	964	Complete	24600	42					83	CA
1018A				1957A	-00:38	1602	Complete							35	AA
1804A				1958A	00:25	1819	Complete	62000	50					94	DC
1905A				1959A	-00:04	9009	Complete	25000	52					45	DA
1937A				1959A	-00:18	117	Complete	78700	45					78	RA

Events FAMFDM Alerts Remarks

Event Time Flight Orig Remarks

27 Mar 19:57 0109

27 Mar 19:36 0109

27 Mar 19:25 0109

27 Mar 19:25 0109

27 Mar 19:23 0109

27 Mar 19:23 0109

27 Mar 19:13 0109

27 Mar 19:13 0109

ALL FLIGHT LEGS 20:50 GMT

(b) 500 Aircraft Airline

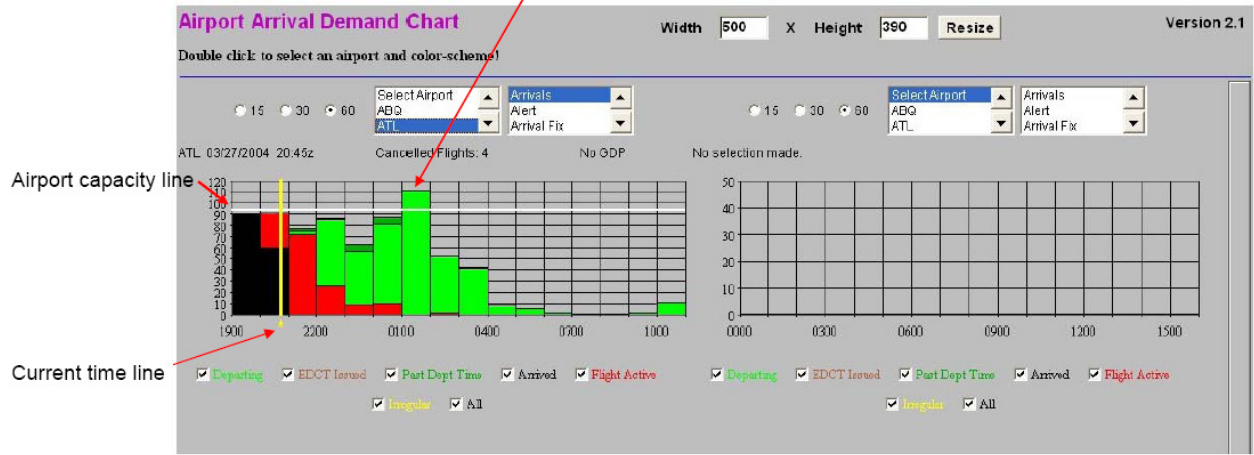
Figure 17: Artifact Models of Schedule Monitors



## Tool provided by the FAA via the web

- Shows previous airport demand
- Current airport demand
- Predicted airport demand

- Predicted demand exceeds capacity
- Cue to sector manager



**Figure 18:** Artifact Model - Predicted Airport Demand

and departing aircraft. Aircraft predicted to arrive or depart significantly behind schedule can be highlighted automatically by the computer program. Additionally, it is possible to sort the “problem” flights so that they stay at the top of the schedule monitor.

Figure 18 shows another tool used by AOMs to determine future air traffic loads, the Airport Arrival Demand Chart. This tool is provided directly by the FAA and is available to everyone via the internet. It allows AOMs to assess the future airport arrival or departure load, and to adjust their tactics accordingly. For example, if the arrival rate exceeds the runway capacity for a single time block, then no drastic actions need be taken. However, if the runway capacity is exceeded for several time blocks in a row, then action needs to be taken to determine how these delays will affect the rest of the airline’s schedule. Likewise, if the capacity has been lowered due to weather it is an indication that the FAA will implement ground delay and ground stop programs. This tool allows the airlines to anticipate ATC flow control actions which will be implemented at a higher level and potentially impact them. In this way they may decide to initiate a departure push over an arrival push to keep their aircraft from being caught on the ground.

### *Contextual Control Modes*

The use of a particular artifact or tool depends on the AOM's CCM. The Predicted Airport Demand chart, shown in Figure 18, is primarily used in the Strategic modes, as it allows the AOM to get a better idea of the upcoming traffic load at a specific airport. AOM's in Opportunistic modes, on the other hand, are much more likely to use the text-based terminals directly to quickly find the information. They are not interested in the upcoming traffic load because they are worried about problems with much more immediate consequences.

#### **4.2.3 Cultural Models**

The purpose of a cultural model is to understand the cultural forces which impact both the work environment and the work itself. In a cultural model the main influencers on a position are represented, be they people, policies, values, preferences, or points of pride. In addition, the specific topic of influence and direction of that influence are shown. The cultural models for Airline Operational Managers are illustrated in Figures 19 - 22. It is clear from the models that there were significant cultural differences between the largest airline and the other three.

As the 700 aircraft airline is one of the largest US air carriers, there is a much higher level of job compartmentalization than at other airlines. Consequently, OCC personnel tend to only interact with a small number of other OCC personnel – usually defined by their job description. For example, the AOMs coordinate rerouting in response to irregular operations. They work primarily at the level of individual flights and coordinate heavily with crew schedulers, ramp managers (for their specific hub/stations) and maintenance coordinators. While they deal with the consequences of the ATC Coordinators and even rotate through that position, they do not interact with the ATCC position. Within these positions there is an undercurrent of tension as each individual tries to find a solution which best fulfills his individual goal. In some cases the AOM has final say, but in most cases the AOM actually must defer to the maintenance coordinators or the crew schedulers, if either claims that a suggested solution cannot be accomplished. The give and take between all of these positions, however, is highly dependent upon the situation as periods of highly

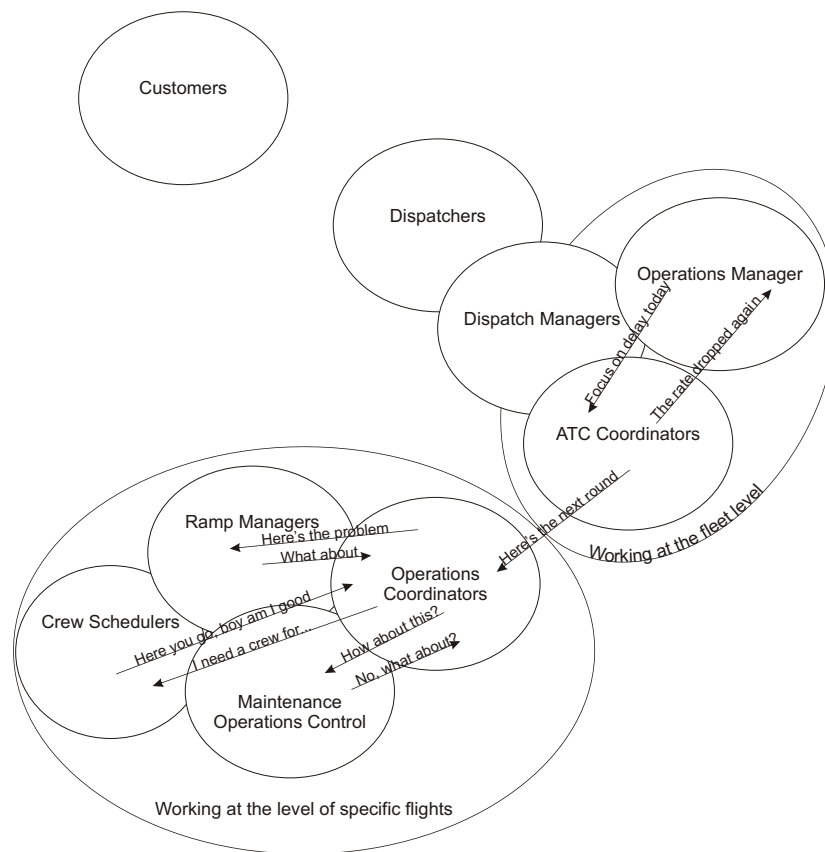
irregular operations often lead to greater flexibility by all parties in cooperating with the AOM.

Most of the AOMs are very senior personnel with an average of over 20 years with the airline. As they have been successfully performing their jobs for several years now, they see little need for increased automation, preferring the systems that they know and understand to newer systems. They are not, however, opposed to enhanced automation that aids their jobs, such as a cancellation advisor which aids with the strategic thinning of the schedule due to severe schedule disruptions, e.g. adverse weather conditions.

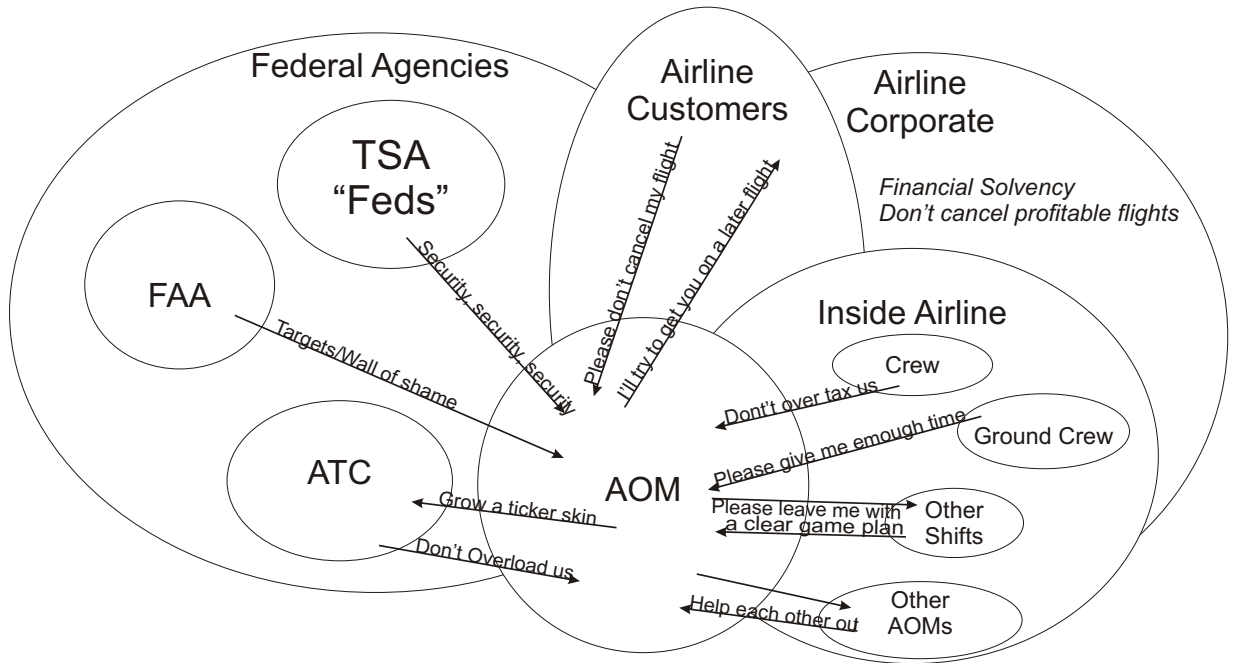
What is particularly interesting about this model is what is lacking. During the inquiry very little managerial oversight or pressure was felt or indicated by the OCC personnel. Perhaps this is the result of having successfully weathered the civil aviation downturn of the early 2000's: Everyone seemed to be acutely aware of the the airline's stock price. Similarly absent were customers or a dedicated customer advocate, although customers were specifically accounted for in several of the in-house optimization tools.

The cultural models for the other three airlines indicate that the OCC personnel were much less fragmented. For the 500 aircraft airline, the only real tension found in this study was between the air traffic controllers and the AOMs in terms of the perceived amount of traffic the air traffic controllers should be able to handle. AOMs often expressed their frustration at limitations imposed by the FAA and the belief that the limitations were excessive to the point of sometimes being motivated by a desire to "share the pain." (That is, to make sure that all airlines suffered equally illustrates regardless of whether the situation warranted it.) For the 100 aircraft airline the model revealed a disconnect between the maintenance department and the rest of the OCC. For the 50 aircraft airline, the major cultural tension existed between the OCC personnel and the information technology department. After a series of technological failures in the OCC, the OCC personnel had a great deal of mistrust of the information technology department's abilities.

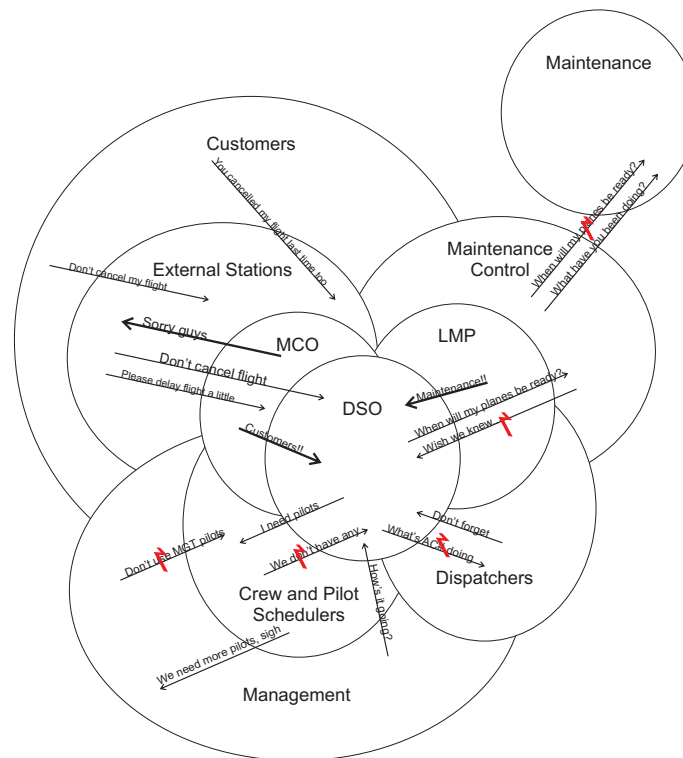




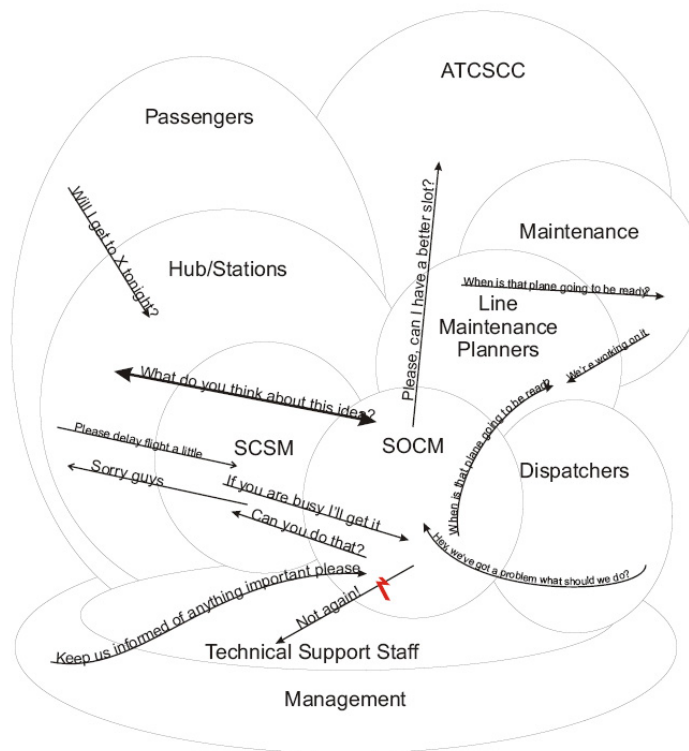
**Figure 19:** Cultural Model – 700 Aircraft Airline



**Figure 20:** Cultural Model – 500 Aircraft Airline



**Figure 21:** Cultural Model – 100 Aircraft Airline



**Figure 22:** Cultural Model – 50 Aircraft Airline

### *Contextual Control Modes*

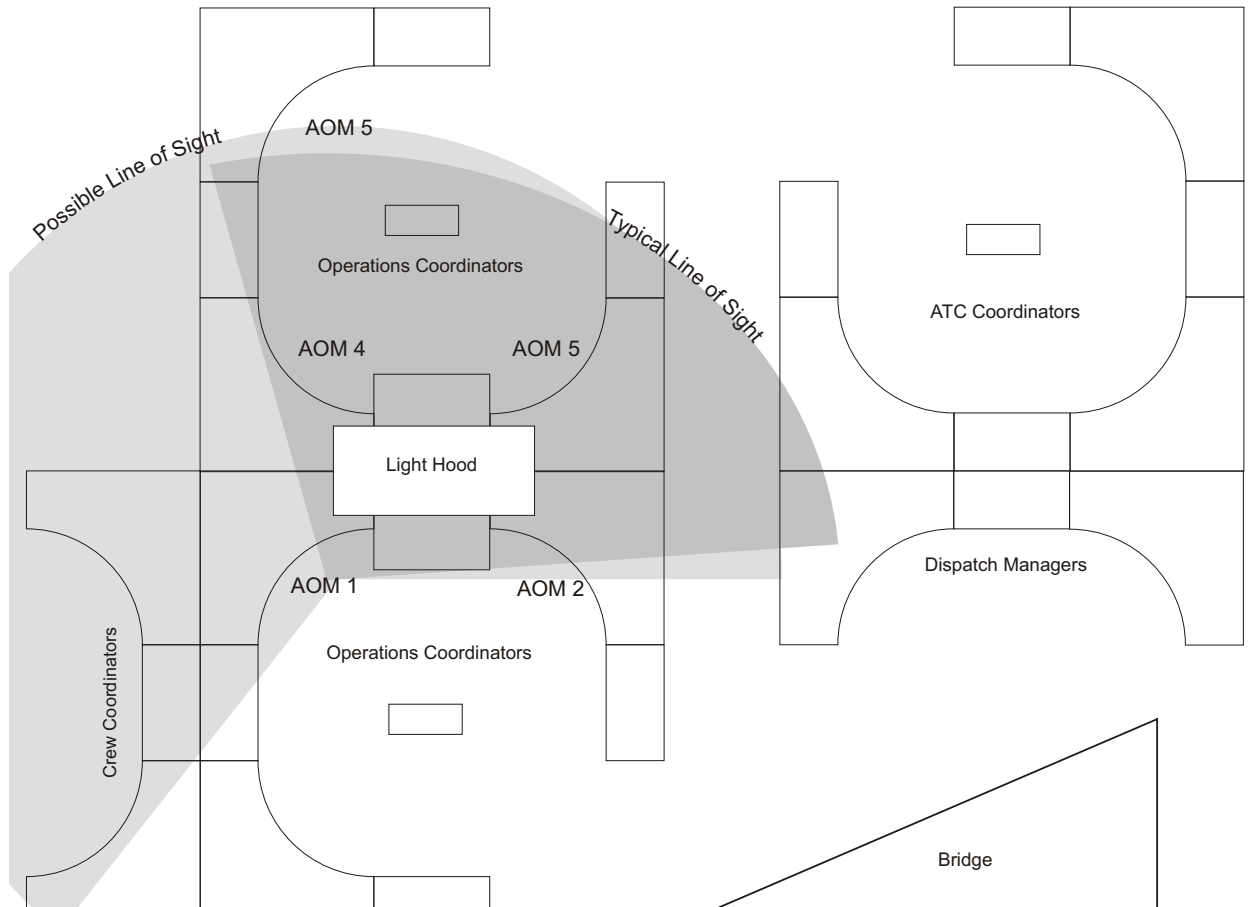
The cultural models illustrate the different stake holders and their influence on the AOMs. As the AOMs transition from Strategic through Tactical and into Opportunistic the stake holders and their messages get filtered out until only the most important messages and influences are left. These are usually the bare basics of keep the airline running by keeping the schedule together in terms of pairing aircraft with crews. The assumption is the passengers will be there waiting when the aircraft and crews are ready to go. At this point all notions of maintenance (beyond safety critical systems that is) and cost are irrelevant. Conversely, in the Strategic mode all stake holders have influence and their needs are weighed with the day's reality and a solution is sought.

#### **4.2.4 Physical Models**

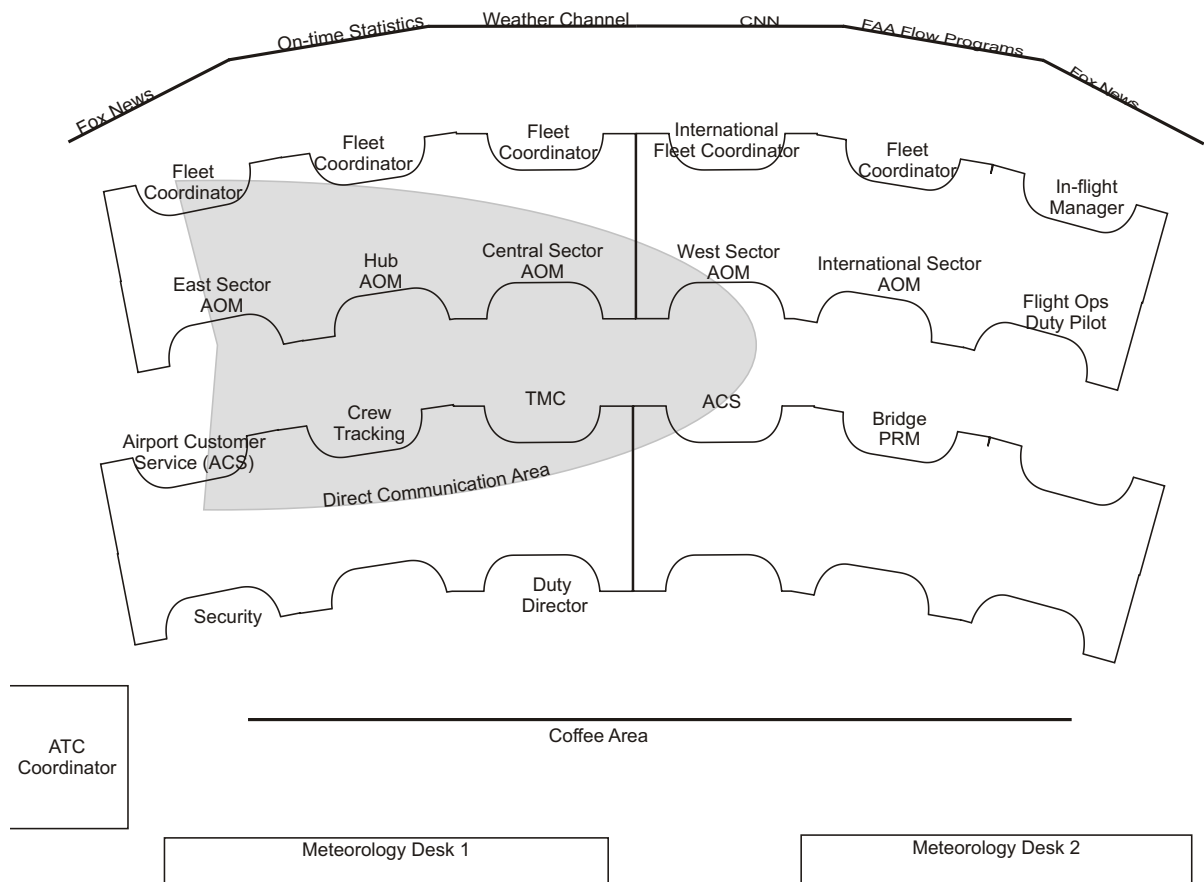
The purpose of the physical model is to depict the physical environment in which the work takes place and to detect any physical barriers to productive work. The physical models for the airlines are shown in Figures 23 - 26. Both of the larger airlines have multiple AOMs co-located so as to increase awareness and to facilitate coordination. Additionally, they have placed the crew schedulers nearby. In the smaller airlines, as there is only one AOM, the AOM is seated next to the customer service representative and line maintenance planning. The dispatchers are also close at hand as are the flight and cabin crew schedulers. In all cases the individuals expected to work most closely together are situated near each other, often within easy hearing distance. As the workstations are manned 24 hours a day by two or three shifts of people, most of the customization of the workstations is limited to the software settings, monitor angle, fan angle and on-screen placement of various software tools.

#### **4.2.5 Sequence Models**

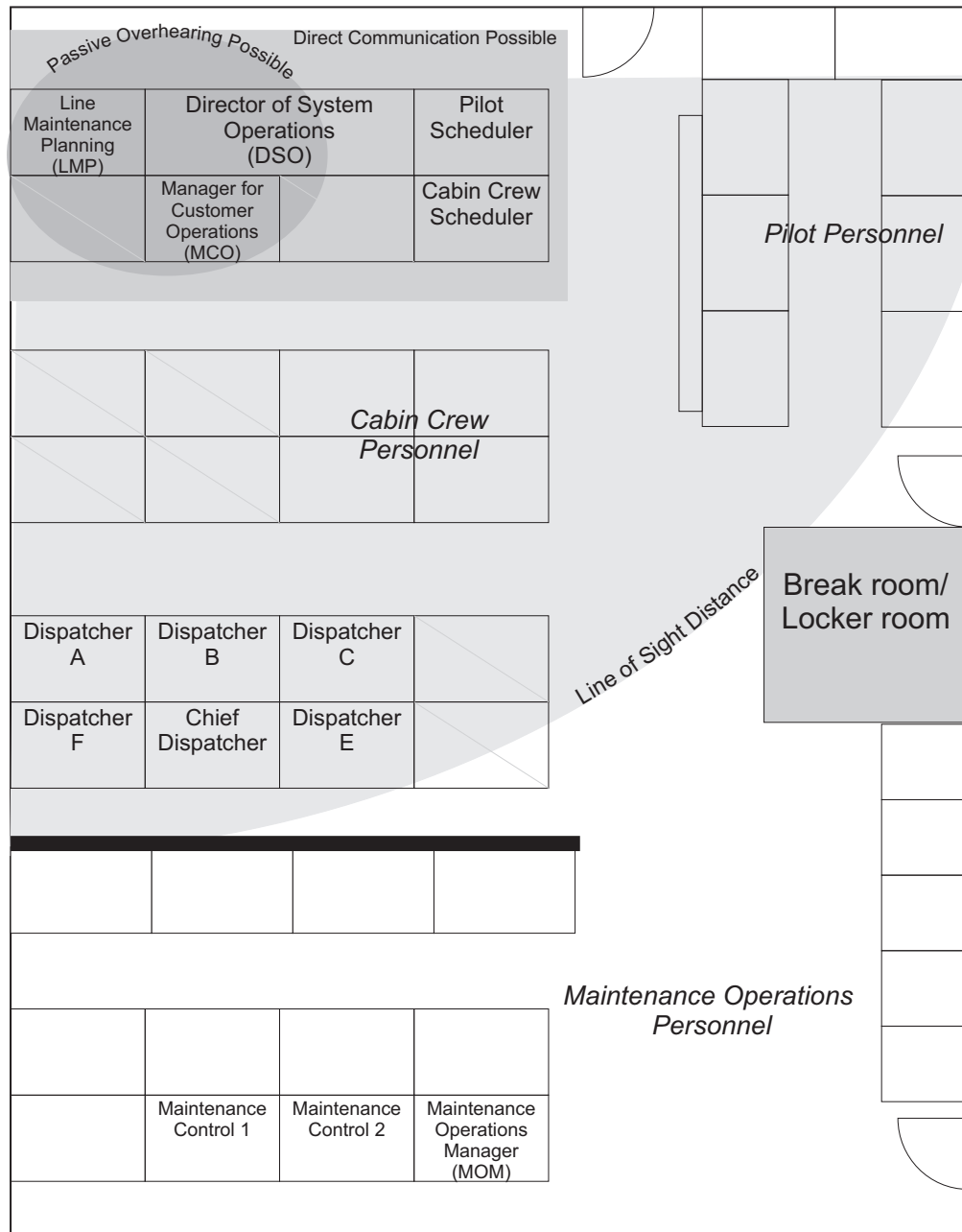
The purpose of the sequence model is to examine procedures used by individuals to complete their work and to examine the motivations behind the actions taken, similar to many forms of task analysis. Sequence models are divided into two columns. The left column contains



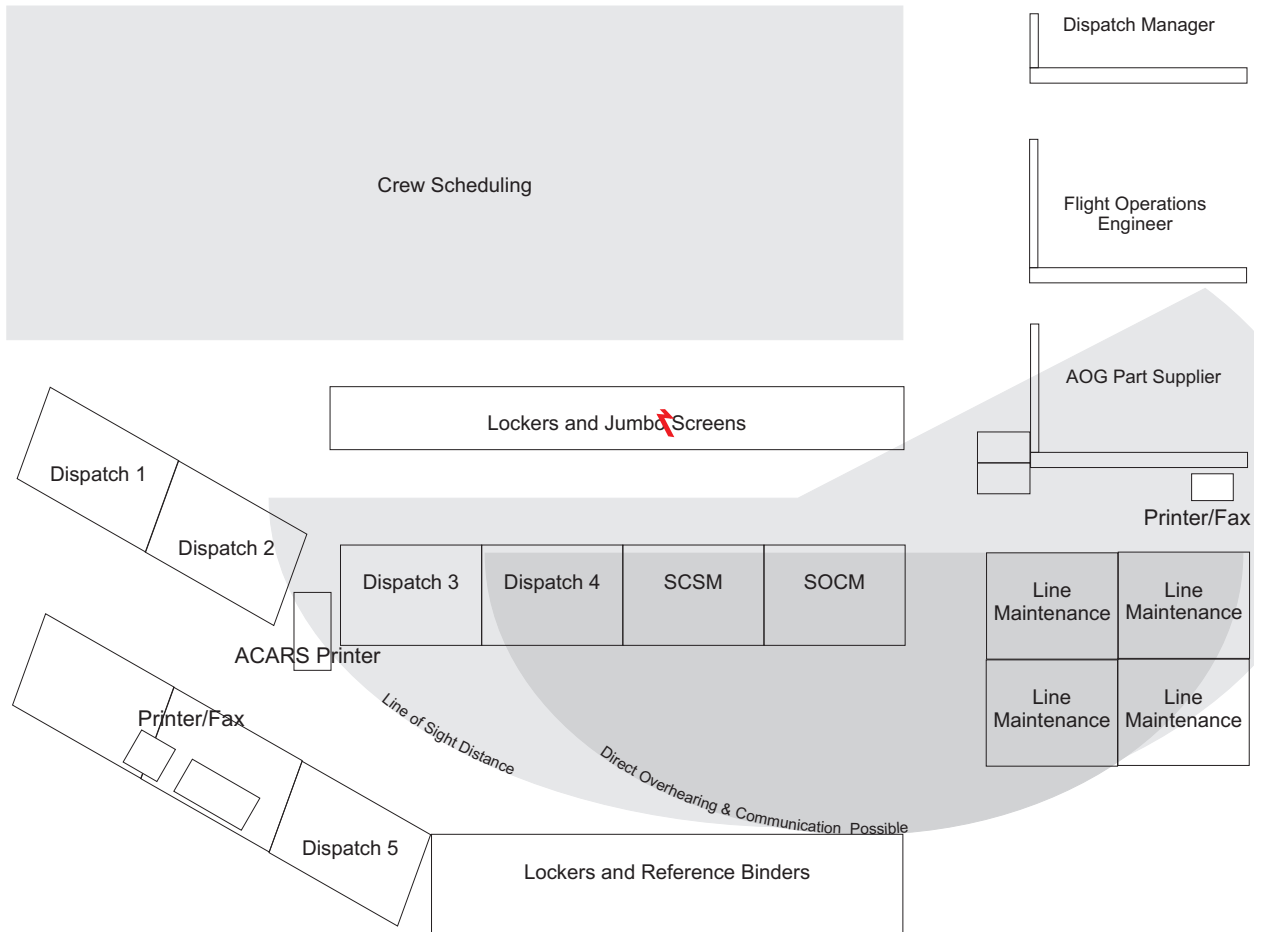
**Figure 23:** Physical Model – 700 Aircraft Airline



**Figure 24:** Physical Model – 500 Aircraft Airline



**Figure 25:** Physical Model – 100 Aircraft Airline



**Figure 26:** Physical Model – 50 Aircraft Airline



the sequence's trigger and the intentions behind each action; the right column contains the sequence actions.

Two sequence models are presented below in Figures 27 - 34 to illustrate the tasks that AOMs perform. The sequence model is arranged in chronological order from top to bottom. The left hand column describes the motivations and intentions for the actions described in the right hand column.

The first sequence model, as seen in Figure 27, describes a task in which aircraft arriving into the hub airport were re-sequenced by the air traffic controllers at the request of the AOM. This sequence of actions was triggered by a call from the airline station manager pointing out that one of the arriving aircraft was significantly behind its scheduled arrival time and that, unless action was taken, most of the passengers onboard would miss their connections. The AOM coordinated the re-scheduling of the airline's flights (including all associated commuter airlines) to get this aircraft into the airport in time to allow the passengers to make their connections. (This meant moving this particular aircraft to the front of this airline's queue of airplanes to land.) This sequence is a primary example of how AOMs and air traffic control often work together to maintain the efficient flow of people and goods through the NAS.

Figure 28 describes an equipment swap, a task performed multiple times each shift. Figure 29 describes a more complicated equipment swap where the seemingly available aircraft chosen for the swap is actually unavailable, but not listed as so by maintenance. This practice of not reporting an aircraft as out of service until it is paired to a flight is common because it reduces the official number of aircraft charged to maintenance. However, as the aircraft are not actually available it often leads to additional work by the AOMs, with frustration and ill will between the AOMs and the maintenance coordinators. Both sequence models illustrate the extent to which the AOM actually coordinates between all of the interested parties, instead of operating on their own.

Whereas Figures 28 and 29 show how some problems are routine and can be easily handled, the final sequence model as shown in Figure 30 demonstrates that some problems are large enough that they take up almost all of the AOM's time and energy over a short but

- **Trigger:** Delta Tower Call
  - Indicated that an aircraft was significantly behind its scheduled arrival time
- **Intent:** Verify that aircraft is in trouble & if so plot solution
  - Checked graphical location of aircraft on radar display
  - Pulled up info on aircraft on the text-based window
- **Intent:** Aircraft will be OK if it can be brought in ahead of all other Delta traffic
  - Got up and went to talk to the FAA contact to ask if the aircraft can have priority
  - FAA contact will talk to his counterpart with the commuter airline
- **Intent:** Make sure that the passengers make their connections even if it means holding other aircraft for a few minutes
  - Calls dispatcher to tell them about connections so dispatch might hold the planes and allow the connections to be made
- **Intent:** Keep the Delta Tower up to date
  - Calls Delta Tower back and updates him of current status
- **Intent:** Make sure that the plane has a place to go when it gets down
  - Checks the gate availability

**Figure 27:** Sequence Model - Bring Plane in Ahead of Others

**Trigger:** OC notices a problem on the SM that can be resolved by swapping equipment.

- |   |   |
|---|---|
| <b>Intent:</b> Needed to verify that a crew was available before looking for an aircraft. | Asked crew scheduling for a new crew<br>Crew scheduling found an available crew |
| <b>Intent:</b> To determine the availability of an alternative aircraft                   | Found a new aircraft for trip using the station schedule print outs             |
| <b>Intent:</b> To verify that this swap will not cause maintenance difficulties           | Called MOC to check validity of plan  |
| <b>Intent:</b> To alert ramp manager of equipment swap                                    | Called the ramp manager   |
| <b>Intent:</b> To advise interested individuals of equipment swap                         | Sent electronic message to explain changes                                      |

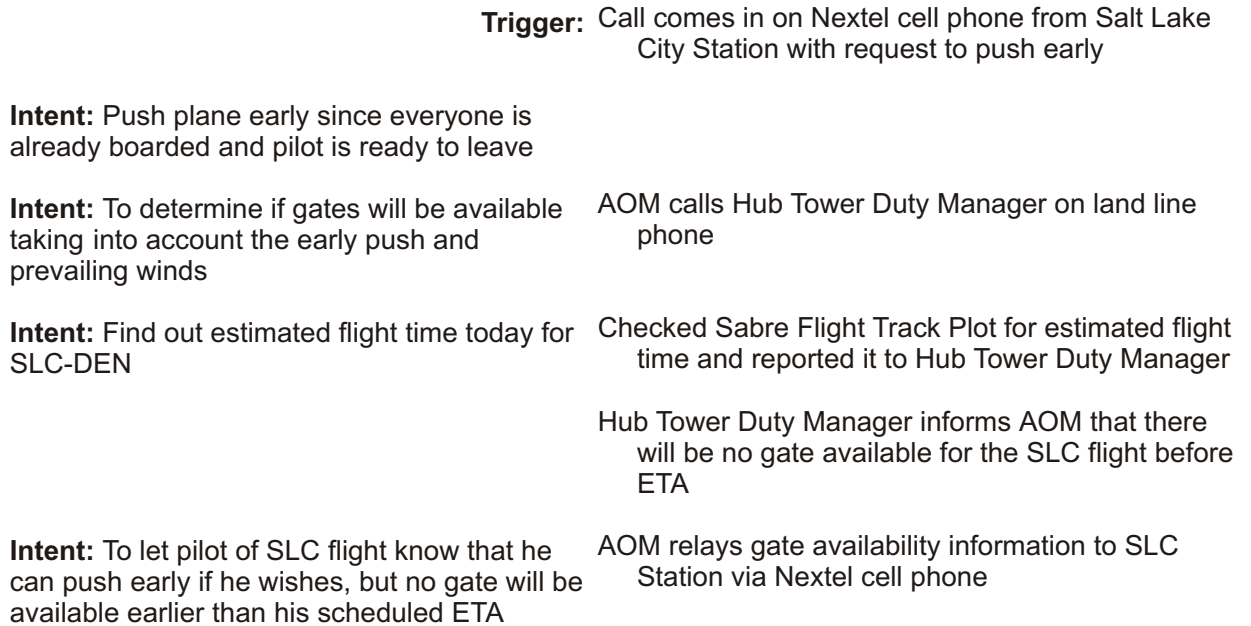
**Figure 28:** Sequence Model: Equipment Swap

	<b>Trigger:</b> Call from Ramp Manager notifying of a new advise time for Ac123 of 1500 from previously posted 0900
<b>Intent:</b> Needed to identify all unscheduled AC, as there isn't any good way to identify available AC	Looked up all 7X7s in at Station in a SABRE terminal
	Found possible AC with a through flight that could be broken into two flights so that it could be used for FLT1243 and a new AC could be found later for the 2nd half of its flight (FLT1067).
<b>Intent:</b> To see if crew schedule is amenable to breaking the through flight	Used SABRE terminal to look up crew sequence
<b>Intent:</b> To verify that this swap will not cause maintenance difficulties	Called MOC to coordinate new AC for FLT 1067
<b>Intent:</b> To advise interested individuals of equipment swap	Sent out message to swap break FLT 1067
<b>Intent:</b> To get them to put swap in computer system	Called MOC and told them to link up FLT 1067 (first half with FLT 452)
<b>Intent:</b> To inform OC that despite earlier coordination and the appearance that AC 055 is available, actually it is not	MOC calls back to say that the AC the OC has put on FLT 1243, while listed as unscheduled is actually not available, please use AC 075 instead.
<b>Intent:</b> To advise interested individuals of equipment swap	Sent out new electronic message to alter swap

**Figure 29:** Sequence Model: In Service Aircraft Unavailable

	<b>Trigger:</b> Bird-strike on AC 888 – probably damaged radome
<b>Intent:</b> Work out what to do as soon as possible if we have to cancel flight	(0818)MCO – called out solution AOM – wrote solution down on piece of paper AOM – walked over to explain plan to Pilot and Crew Scheduling MCO & AOM continue discussion about other alternatives while Pilot and Crew Scheduling work on finding new crews
<b>Intent:</b> Wanted to verify damage enough to cancel	(0824) AOM calls maintenance Verified big damage MCO – looks up impact on SABRE and calls station  (0825) Maintenance called Possibility of ferrying AC with radome damage MCO – asked to wait 5 minutes to cancel next flight
<b>Intent:</b> to try not to cancel follow on flights or current flight	(0826) MCO – calls sister company and finds they have an RJ on standby AOM – types into log MCO & AOM – discuss implications plan for AC to be out for 24hrs
<b>Intent:</b> to come up with a contingency plan	(0831) AOM – asks Pilot Scheduler to find crew to ferry AC home later in the day AOM – checked VisOps for flights to cancel AOM – cancelled three follow on flights MCO – called stations AOM – interrupted by maintenance slip on another AC  (0836)Maintenance calls Found radome, thinking of maintenance ferry Ready in 3 hours after arriving
<b>Intent:</b> Wanted everyone to be informed	(0840)AOM – told MCO & Pilot Scheduler about possible ferry MCO – briefed AOM about PAX situation from bird-strike
<b>Intent:</b> To inform rest of airline	(0842)AOM – put in an ETD on the Flight Information System
<b>Intent:</b> Trying to figure out what the situation will be tomorrow with pilots as this will probably drag on until then	(0845)AOM – wrote up issue in log AOM – went to ask about tomorrow's crew situation
<b>Intent:</b> Curious why the plane returned to the gate – not a good sign	(0851)MCO – briefed AOM that sister company was not going to loan spare (0856)AOM noticed block turn on Flight 333 due to door issue Looked up agent to call on SABRE Called agent
	(0859)Updated log AOM – dealt with some other issues
	(0903)Maintenance called AOM Not able to ferry – too much damage No shipping information yet on how long AOM – delayed some flights affected AOM – consulting VisOps for anything else to be done
<b>Intent:</b> Trying to find some way to keep from cancelling so many flights	(0911)Maintenance updated ready time on another AC (Can use it to cover some flights)  (0912)Call from station AC with Flight 333 does not look good
<b>Intent:</b> To take some load off of the AOM and to cover Flight 333	(0913)LMP handles swap to cover Flight 333
	(0915)Maintenance calls about Flight 333 damage Door damage out of spec – it goes out of service AOM – checks load on SABRE, uses VisOps to find options AOM asks MCO about options
<b>Intent:</b> Trying to find some way to keep from cancelling flight that follow Flight 333	(0918) MCO advises on which is best to cancel AOM – asks LMP to make swap AOM – updates log AOM – sends flash message  (0923) Maintenance calls AC 888 has a new ready time of 1900-2000

**Figure 30:** Sequence Model: Bird Strike



**Figure 31:** Sequence Model: Early Push Request

significant period. Figure 30 shows the activities of the AOM, customer service manager (CMO) and Pilot Scheduler in response to a bird strike. The actual times for each event are listed in parentheses. The bird-strike occurred shortly after takeoff and the plane returned safely to its origin. As the sequence model shows, there was an hour of intense activity which occupied all of the AOM's time and a significant portion of both the CMO and the Pilot Scheduler. Most of the activity centered around trying to figure out 1) the extent of the damage, 2) an estimate of the ready time, and 3) a set of contingency plans to minimize irregular operations and the resultant passenger disruptions.

Figure 32 shows the sequence of events when an unscheduled maintenance event occurred at the 50 aircraft airline. Notice the close coordination of the AOM and the Tower Duty Manager. This sequence also highlights the extra work involved with actively keeping non-OCC personnel apprized of a fairly routine situation.

Figure 33 shows the sequence of events that occurred when the gate print server failed during a departure push. Without the ability to print out the departure paperwork, several of the aircraft could not legally depart. As the issue was systemic and affected all of the

gates, the AOM, the system customer service manager (SCSM) and the dispatcher seated closest to the AOM all worked on the problem simultaneously. It was quickly clear that there was not much that the AOM could do directly, so when the AOM received a call from a dispatcher scheduled to work later in the day stating that he was ill and unable to come in, the AOM began to work that problem instead. This left the SCSM in charge of the printer outage issue. The problem was exacerbated because it was difficult for the SCSM to reach the gate agents by phone, as they were using their phones to communicate with other airline personnel at the airport. In the end through a variety of means all of the aircraft departed within thirty minutes of their scheduled departure time. It turned out that the printer server had failed because it was on a circuit that had been inadvertently overloaded by a passenger plugging an appliance into an electrical outlet in the main terminal waiting area.

The final sequence model, as seen in Figure 34, describes a task where a partially obstructed access road leading to the fuel farm was discovered to be the cause of delays which, because of the circumstances, could not be avoided. In both of these sequences the goal of the AOM was to minimize disruption to the schedule by coordinating the actions of the airline operational personnel.

### *Contextual Control Modes*

Most of the sequences presented above fall under either the Tactical or the Strategic CCM. However, the first sequence shown in Figure 27 illustrates an AOM operating in an Opportunistic mode. Notice how the AOM does not ask for input into the solution, but simply informs his colleagues of what he needs done to make the solution work. While he asks for a new crew from the crew schedulers, he does not discuss the situation with them, but instead simply requests that they find him a crew. He informs all necessary parties, but does not ask for their input into the decision. Conversely, in the following sequence, Figure 28, the AOM coordinates with the MOC to check the validity of her plan. Had the AOM been in an Opportunistic mode, we might have expected the AOM to simply inform the MOC about the impending change. By coordinating with the MOC this sequence indicates that

	<b>Trigger:</b> Maintenance called LMP advised Flight 497 has a fault and the mechanic meeting the flight needs an hour
<b>Intent:</b> Going to need new AC for Flight 497 or it will push late	(0959) LMP relays information verbally to the AOM
<b>Intent:</b> To gather information about that flight	(0959) AOM located flight on the Flight Track Plot (FTP)
<b>Intent:</b> To advise of issue with AC 329 and to consult about best possible solution	(1001) AOM called Tower Duty Manager to advise of advise time on AC 329 - Gave suggestions to solve problem - Used FTP to search for other available AC - Checked gate location to choose between options - Decided to swap with AC 306  (1005-1007) Received calls and worked on other issues
<b>Intent:</b> To keep Flight 497 on time - To let the dispatchers know that there has been an equipment change - To make sure that the AC swap will not interfere with scheduled maintenance	(1008) Swapped AC 329 and AC 306 - Advised dispatchers of change - Checked maintenance planning sheet for conflicts
<b>Intent:</b> Changes do not affect tonight's maintenance schedule, but will impact tomorrow's unless the an MEL can be worked on tonight	(1013) Called maintenance planning - Asked for early work on MEL tonight - Asked also for an amendment to other maintenance plan
<b>Intent:</b> To keep personnel outside the SOC informed about equipment change	(1016) Wrote email to routing list by cutting and pasting changes from the FTP
<b>Intent:</b> To understand the solution so he can check it for maintenance implications	(1020) LMP asked for clarification about changes AOM explained solution  (1024) SOCM updated shift log

**Figure 32:** Sequence Model: Unscheduled Maintenance

	<b>Trigger:</b> (1041) SCSM received call from Hub, all of the gate printers at the hub not working, neither are the printers working in the supervisor's offices.
<b>Intent:</b> To let the SOC know of problem and to enlist help	(1042) SCSM informs AOM (and rest of SOC as he is speaking out loud) of situation: gate printers down due to a networking problem, IT has been informed and is working on it
<b>Intent:</b> To let AOM and rest of SOC know of major problem during 1030 push – likely impact to operations is high	(1043) Dispatch1 suggests that hardline fax be tried (1042) AOM scans the Sabre Flight Track Plot to determine extent of problem
<b>Intent:</b> To inform that 5-7 flights were being affected and to be prepared for late push	(1044) AOM calls Hub Tower Duty Manager
<b>Intent:</b> To inform AOM that he could not work today and a replacement would need to be found	(1045) AOM received call from sick dispatcher
<b>Intent:</b> To find dispatcher to fill vacancy for later shift, and to leave the network problem to SCSM and dispatchers	(1046) Looked up the SOC Director's phone number, called and received no response; got up and grabbed the duty roster binder and began task of finding a replacement dispatcher, a task that would last until 1206
<b>Intent:</b> To advise out stations of delay.	(1057) SCSM and Dispatch began delaying flights in Sabre Flight Track Plot system
<b>Intent:</b> To get AC pushed as fast as possible	(1058) Dispatch1 suggests using ACARS system to send information direct to the flight deck
<b>Intent:</b> To tell gate agent of ACARS plan	(1103) Attempt to call gate agent; gate line busy, called adjoining gate; called gate again (1107) ACARS taking a long time to send; unrecoverable error – yet it success fully transmitted
<b>Intent:</b> To better understand situation and to brief his pilots a bout reason for the delay	(1108) Chief pilot walked in to SOC looking for information after getting call from pilots; AOM briefed about printer issue
<b>Intent:</b> To advise Concourse Supervisor of future backup plan.	(1111) Everyone else pushed on their own; SCSM devised a procedure using ACARS and called Concourse Supervisor to advise.

**Figure 33:** Sequence Model: Gate Printer Outage



- Trigger: Using the ODT, EMS noticed that a plane out of Raleigh was late for no apparent reason
- Intent: find out what might be causing the delay
- EMS used DLTERM32 to review aircraft's history and found that something had happened at Raleigh when he was not on duty.
- Called a Raleigh to find out what was holding the plane up
  - Found out that an F-18 had crashed by the fuel farm and the wreckage was blocking the road to get fuel trucks to and from the terminal, causing delays
  - Asked to tanker at ATL for the weekend
- Intent: ask for tankering out of Atlanta to minimize overall system delays caused by Raleigh
- Walked to the Duty Director to see if it would be possible to tanker out of ATL for the weekend
  - No, ATL has a fuel shortage problem
- Intent: to inform Raleigh that the request had been denied and why
- Called Raleigh back to tell bad news that they will just have to take the delays
- Intent: to inform his fellow sector managers and to find out if any of them knew, and how he managed not to know about the fuel shortage
- Shouted over to ATL & Central SM stations to tell about ATL fuel shortage
- Intent: to inform follow on crews about the fuel shortage and Raleigh delay issues.
- Wrote down the ATL fuel shortage and the Raleigh tanker delay problems in the SM activity report

**Figure 34:** Sequence Model - Tanker in Fuel

the AOM was operating in more of a Tactical mode.

### 4.3 Summary

In this chapter we have examined the work of airline operations managers at four distinct US airlines using the method of contextual inquiry. Work models illustrate the work from five distinct perspectives: information flow, cultural, physical, sequential and artifacts. Using these models, it has been possible to compare the individual airlines for similarities and differences. While the cultures, computer systems and airline resources are all different between airlines, overall the work performed by the AOMs at each airline is very similar in terms of responsibilities and tasks. Consequently, it is possible to design a cognitive work support system for AOMs at a variety of airlines.

Additionally, the work models have illustrated how the AOM's patterns of activity vary due to contextual features such as the number of spare aircraft and crew available, the status of the national air space system, inclement weather, load factor and time of day. The following chapter examines the work models presented here for design insights and implications and creates a vision to redesign the AOMs work process.

## CHAPTER V

### WORK REDESIGN

The third step in Contextual Design is work redesign, where new work practices are created. “Invention of work practice is based on a foundation of customer data, driven by knowledge of the different available technology and how to apply it to the design. [2] (p.229)”

Accordingly, this chapter is divided into four sections. The first section examines the work models for any impediments to the current work practice. The second section details the visioning process by which a vision of new work practices, facilitated by a CWSS, is captured in a series of vision diagrams. The third section fleshes out the vision diagrams storyboards illustrating the new work practice. The final section summarizes the technology needed to enable the new work practice.

#### ***5.1 Work Model Examination***

The primary method of redesigning work practices examines the work models for hidden (or obvious) insights and issues including concurrently seeking out similar patterns or work structures in related domains for insight. Beyer and Holtzblatt suggest examining the work models for the following issues:

##### **Flow Model:**

Role Switching, Role Strain, Role Sharing, Role Isolation, Process Fixes

##### **Cultural Model:**

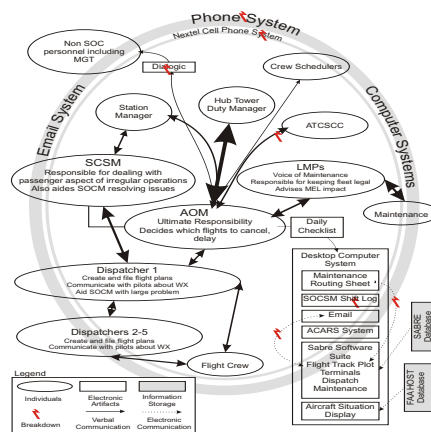
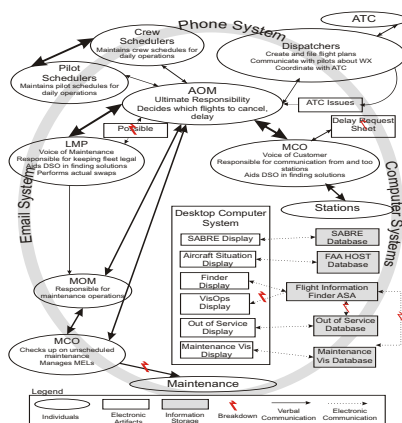
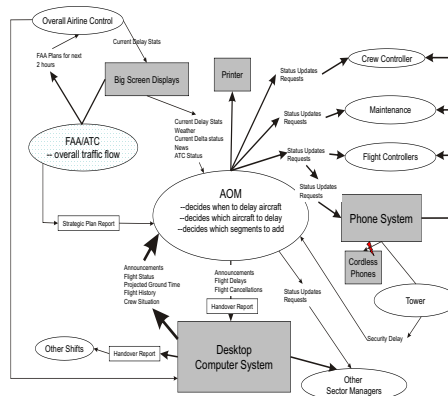
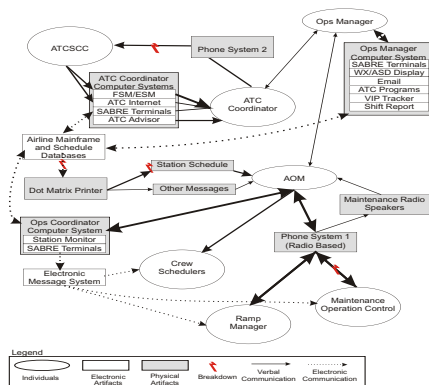
Interpersonal Give and Take, Pervasive Values, Public Relations, Process Fixes

##### **Physical Model:**

Movement and Access, Work Structure, Partial Automation, Process Fixes

##### **Sequence Model:**

Primary Intent, User’s Approach, Unnecessary Steps, Triggers, Process Fixes



**Figure 35:** Information Flow Models

### Artifact Model:

## Information Inclusion, Organization, and Presentation

In addition to these suggestions, I also examined the impact of an AOM's CCM on the work, and examine the role (or lack thereof) of automation in the AOCC.

### 5.1.1 Information Flow Model Analysis

Analysis of the information flow models, This began with identifying the distinct roles assumed by AOMs. The first, and primary, role that AOMs assume is that of a *problem solver*. They are expected to resolve schedule disruptions quickly and effectively. The

problems solving role is intricate as many different factors must be accounted for with each disruption, e.g. flight schedule, cabin and flight crew schedule. The AOMs refer to the source of disruptions as *problems*. Accordingly, they often organize their information searches around a specific problem to fully understand both the nature and impact of the disruption as well as the context in which it is occurring.

The second and third roles that AOMs assume, that of an *information collector* and *information relay*, are complementary. AOMs are constantly gathering information from both proximal and distal colleagues, from a variety of computer databases, from television, and their own senses. Even the level of ambient noise in the command center can be a good indication of the number of concurrent problems affecting an airline, as a greater number of disruptions requires more individuals to communicate with each other. AOMs gather information to 1) help them solve problems and 2) to pass on to others. They pass information on to future shifts, to the rest of the airline through routine teleconferences, and to colleagues verbally, in person, via instant message (IM), or over the phone.

The roles of *problem identifier* and *fleet manager* were two additional roles which were observed only at a subset of airlines. The problem identification role was only taken on by AOMs at the smaller airlines during periods with few disruptions using schedule visualization software to scan for potential problems. If they identified a problem, they then switched roles and began to gather information before switching again to solve the problem. Problem identification at larger airlines did not exist because 1) schedule visualization tools did not exist at these airlines and 2) because they employed tools automatically identifying potential problems and bringing them to the attention of the appropriate person.

The final role was *fleet coordinator*. This observation was made at a single airline and illustrates how work and roles can vary between companies. At this airline each AOM was responsible for a set of aircraft types and any problems needing maintenance or a replacement was his/her responsibility.

With these roles clearly delineated, I was then able to examine the information flow model, in Figure 35 specifically for issues surrounding role switching, role strain, role sharing and role isolation. Each is discussed below. Potential solutions in the form of software

functions/features and process changes were identified, some potentially addressing multiple issues.

### *Role Switching*

Role switching is defined as switching roles, the goal structure and ways of operating associated with the roles. Excessive role switching is considered to be unproductive as it leads to role strain. In the airline operations environment AOM role switching happens frequently. Role switching was primarily a problem between information collection and problem solving. Information collection tended to interrupt the problem solving role either because a new problem was brought to the AOM's attention, or because, while the AOM was working on solving a problem, she discovered that she needed an additional piece of information. Often the role switching is reinforced by the artifacts supporting only one role at a time.

### *Role Strain*

Role strain is defined as having too many roles within a short period of time. Role strain is often a problem with AOMs during periods of high schedule disruption, where the roles of problem identifier and information relay are often shed. This can delay 1) identification and resolution of new problems and 2) recording of significant events in the shift log. Delayed identification is especially common for the smaller airlines which do not have any dedicated problem identification systems. These periods typically coincide with AOMs transitioning to a lower CCM, e.g. to opportunistic from tactical. Additionally, the role of information collector is also streamlined during periods of role strain so that only the most necessary and expedient forms of information were collected.

### *Role Sharing*

Role sharing is defined as multiple people with different job responsibilities all playing a single role. In airline operations this was primarily a problem for the role of problem solving, which is often shared between the AOMs, the crew schedulers and the maintenance managers. While all of them may attempt to solve the same problems, they are interested in different subsets of the problem and frequently have access to different computer systems

specialized to help them with only their aspect of the problem solving process.

For example, a problem originating with a late crew will impact not only the current flight but also subsequent flights by that aircraft, which will then be flown by a different crew. Additionally, if the aircraft scheduled on that flight requires maintenance that evening it needs to be scheduled to arrive at a certain destination by a certain time. The crew schedulers will attempt to solve the problem by finding an alternative crew for either the first flight or the subsequent flights. The maintenance manager will attempt to ensure that it makes it into a maintenance base with the resources to conduct the maintenance required. The AOM will attempt to find an alternative aircraft for the subsequent flights as well as maintaining responsibility for the overall problem and coordinating with all involved.

AOMs operating in a strategic CCM are well suited to deal with the pressures of role sharing; in fact, where acting as an information relay they coordinate the problem solving process. AOMs operating in the tactical CCM, however, may find that they do not have the time to serve as the information relay and instead delegate solving one problem to one of their colleagues while they move onto the next problem. AOMs operating in an opportunistic CCM may take an alternative tack and refuse to share roles; instead they solve the problem with little input from their colleagues.

### *Role Isolation*

Role isolation occurs with roles which are so specialized that they do not understand the work of others. Individuals in larger organizations are more likely to suffer from role isolation than individuals at smaller organizations. In airline operations, role isolation was particularly a problem between the maintenance managers and the AOMs and was especially acute at larger airlines. The maintenance managers sought to schedule maintenance meet federal requirements, to keep the aircraft in working order and to fix any problems as quickly as possible. These goals often clashed with the AOMs' goals of maintaining the published schedule as closely as possible, as this often requires swapping aircraft between flights such that the swapped aircraft might not spend the night at the location originally scheduled for them to receive maintenance. Role isolation is also a problem to a lesser

extent between the AOMs and most other airline staff such as upper management, gate agents, station agents, etc. While outwardly role isolation appeared to become worse at lower CCMs, role isolation actually remained constant. The AOMs were aware that their decisions may negatively impact the work of their colleagues, however there wasn't time or other resources available to allow the AOM to take additional goals into account.

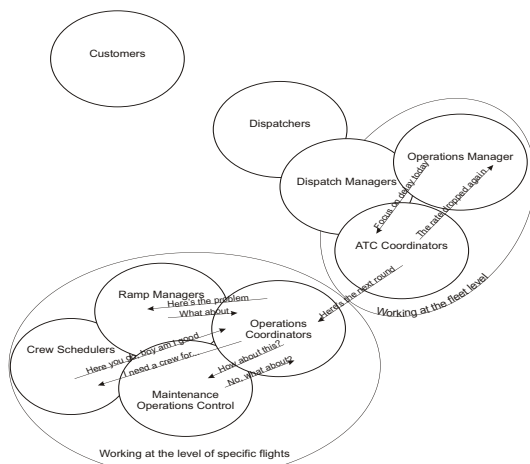
### *Design Insights*

Potential solutions to aid with role switching and role strain include designing the CWSS structure to mirror the problem-based work structure. A problem-based CWSS would allow new problem cases be created in the CWSS with any available information. The CWSS would then automatically assemble the information relevant to each problem in a single place. The CWSS would also organize the multiple problem cases and, if an AOM was interrupted while working on one problem, (e.g. role switching), the CWSS would automatically save all of the work done thus far and allow him or her to come back to the problem when ready. The CWSS would allow other individuals to identify and enter problems and then assign them to specific AOMs (or vice versa) to help coordinate assignments. Further, the CWSS would shoulder most of the burden of recording AOM actions and reporting them to others and to the daily shift log.

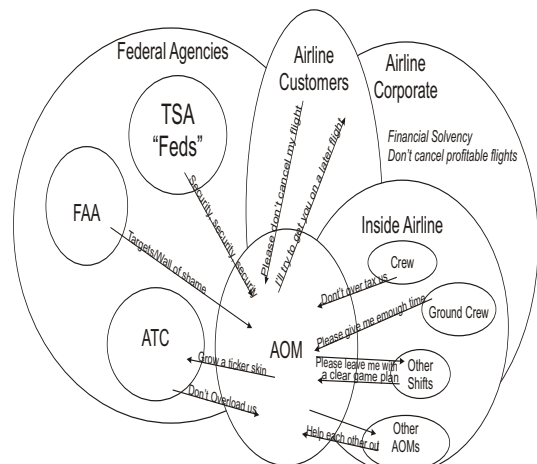
Potential solutions to role sharing and role isolation problems should include a mechanism for sharing "problem" files between different types of users of the CWSS. For example, if the CWSS were designed with multiple interfaces tailored to AOMs, Crew Schedulers and Maintenance Managers they could send files containing essential information to each other. Then these individuals could see all of the potential solutions, comment on the acceptability of different solutions, and suggest new solutions.

### **5.1.2 Cultural Model Analysis**

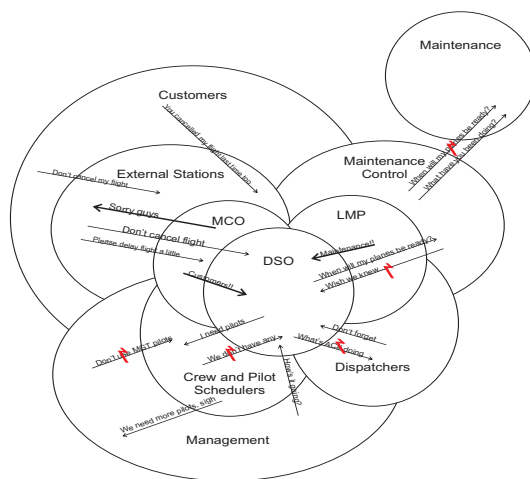
Next I examined the cultural models for issues with interpersonal give and take and with pervasive values. Examples of issues with interpersonal give and take include situations where specific individuals or organizations prefer to pursue goals which further their cause at the expense of the overall organization, thus causing problems for the rest of the organization



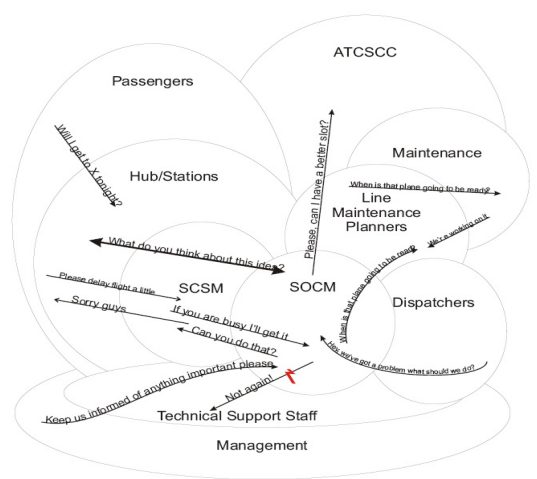
(a) 700 Aircraft Airline



(b) 500 Aircraft Airline



(c) 100 Aircraft Airline



(d) 50 Aircraft Airline

**Figure 36:** Cultural Models



and often resulting in discrepancies between the prescribed work practice and the actual work practice.

### *Interpersonal Give and Take*

The cultural model revealed that interpersonal relationships are very important to the smooth operation of an airline. I believe that the emphasis on maintaining strong interpersonal relationships is the AOM's mechanism to combat problems brought about by role isolation and role sharing. In particular, I was struck by the importance of verbal communication. Unlike electronic communication, verbal communication conveys emotion through tone of voice and readily exchanged pleasantries. In a stressful environment it is important to ensure that neither the content of the message, nor the emotions behind the message are misinterpreted. Tone of voice and small pleasantries (which build up over time into a personal relationship) minimize these misunderstandings. When the AOMs were operating in opportunistic CCMs, however, they dropped these pleasantries and streamlined their conversations to extract information in the shortest amount of time possible.

Additionally, AOMs aid their colleagues when their workload allows. AOMs operating in both the tactical and strategic CCMs often take on the duties of their colleagues for short periods of time, such as when one AOM takes a break. However, for ongoing problems, even when operating in high CCMs, for other AOMs do little more than take messages because of the difficulty of explaining (verbally) all of the nuances of a partially-solved problem. Further, at present there is no way to know who is working on what problem other than general rules of task allocation by geography or aircraft type.

### *Pervasive Values*

The primary pervasive value was one of overriding safety and not taking risks. The other pervasive value was that of keeping good shift records. This activity took up a significant amount of time as the shift log was updated continually. Beyond these two shared values, pervasive values varied between airlines. The AOMs at smaller airlines tended to be more motivated by small delays and individual passenger issues than AOMs at larger airlines, as smaller airlines have neither the additional personnel nor the schedule capacity available at

larger airlines.

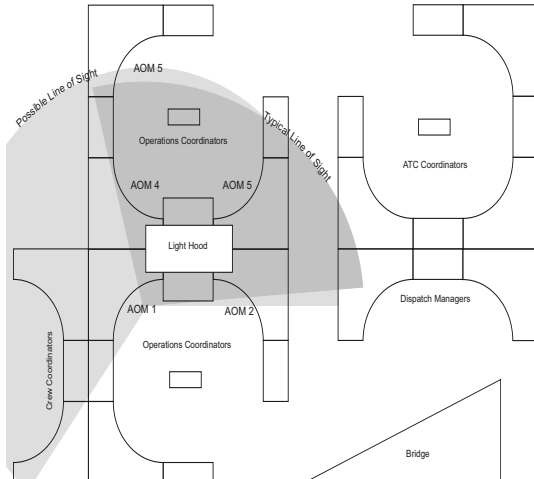
### *Design Insights*

The first issue, personal give and take, suggests a need to maintain verbal communication in the new work structure which in turn suggests that the CWSS and the phone system should facilitate the creation and maintenance of good personal relationships. By integrating the duty roster into the CWSS the correct person's picture and information should be displayed thereby reinforcing the sense of knowing an individual and not just a position; the CWSS can also facilitate verbal communication by providing an easy mechanism to dial the correct person.

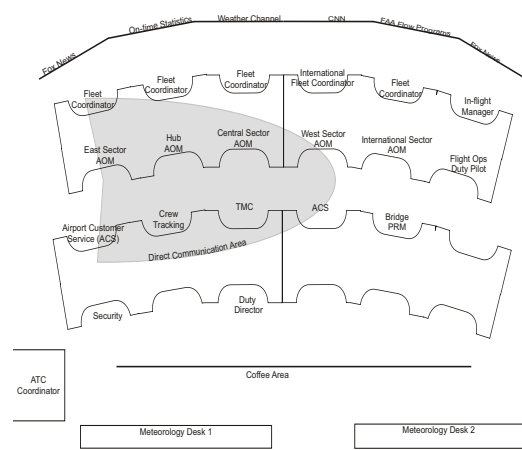
The second issue of facilitating workload sharing could also be addressed by a sharing problem information and CCM mode between individual AOMs via the CWSS. This would allow AOMs and the shift manager to better understand both the current task loading each AOM is under and their operational mode. This information would help to inform the assignment of new cases, or in certain situations even to reassign cases to other AOMs thereby redistributing the task loading. For example an individual who was in a strategic operating mode working on a single case might be spared the addition of additional cases, if the first case was deemed to be high impact. Alternatively, if an individual was in an opportunistic operating mode working on several cases he might be spared the introduction of a complex or high impact case, but instead given simple cases.

To better facilitate the role switching and to alleviate the role strain, the CWSS should facilitate the inherent changes which take place in the information flow model as the AOMs take on different roles and different operational CCMs.

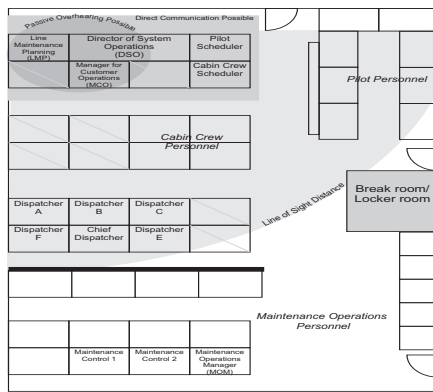
To bolster the value of maintaining good shift logs, the CWSS can also record issues into the log automatically. AOMs might still wish to augment the log to provide further explanation, but the actual actions taken by an AOM over the course of a shift, the problems that arose and the issues to be aware of could all be automatically recorded by the CWSS and parsed into useful reports for both the following shift and for other individuals. This information about the problems faced by the AOMs could also be used in training. The



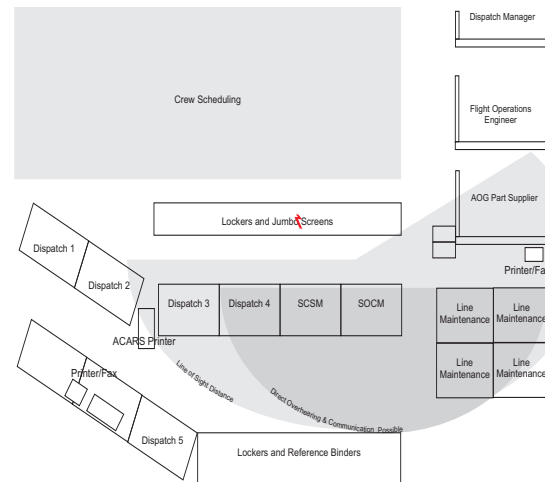
(a) 700 Aircraft Airline



(b) 500 Aircraft Airline



(c) 100 Aircraft Airline



(d) 50 Aircraft Airline

**Figure 37: Physical Models**

automation of the shift log would be especially useful when AOMs are operating at the opportunistic level.

### 5.1.3 Physical Model Analysis

I examined the physical models for issues with movement and access, work structure, and partial automation. I was particularly interested to see if the physical arrangement of the AOMs and their close colleagues helped or hindered the work process.

### *Movement and Access*

The physical layout of each operations center was unique, see Figure 37. In an AOCC the goal is to minimize the movement necessary to access the important people and information. This is primarily achieved by co-locating individuals with the same or complementary responsibilities. The two smaller airlines had only one AOM who was seated near both the customer service representative and a maintenance manager or scheduler. The two larger airlines had multiple AOMs who were seated near each other and near the crew schedulers. The customer service and maintenance representatives were situated much further away - in one case, in a different state. The AOMs at smaller airlines also relied heavily upon both phone and IM systems to communicate to individuals outside of the operations center.

### *Work Structure*

Individuals commonly structure their physical environment to aid them with their work. Consequently, insights about the structure and nature of the work can be found by examining the space in which work occurs. Indeed, a great deal of specialization has taken place in the overall structure of the AOCC. The AOCCs at the larger airlines have been specifically designed to place key individuals in close proximity to make the schedule recovery process more efficient and to reduce role isolation. For example, at the 500 aircraft airline, the AOCC has a dedicated bridge where all of the AOMs sit along with the flight and cabin crew schedulers and maintenance representatives. Individuals sitting in the bridge, have specially designed work stations that boast three computer monitors, a radio phone system, and a continuous feed printer. In the 700 aircraft AOCC the AOMs have a special desk area with extra lighting to facilitate their use of schedule print-outs. Additionally, each cluster of desks has its own printer, eliminating the need to walk to pick up print-outs. While the furniture of smaller airline AOCs is not as specialized the organization of workstations gives priority to keeping the AOM, customer service and maintenance coordinators in close contact. The most variable piece of equipment in AOCCs is the location of the printer. At the larger airlines, each AOM had access to a printer at their work station. At the smaller airlines only one printer was available for the entire AOCC and is located near the

dispatchers. The printer location indicates the relative importance of printed material to the work of AOMs.

Unfortunately, as an AOMs station must be manned 24 hours a day, each work station is itself fairly generic – consisting of a desktop, computer with dual monitors, and one or two phone systems. AOMs are not able to greatly alter their physical work environment as they share it with at least two other shifts. Little specialization is done other than the posting of important phone numbers, and the ubiquitous presence of scratch paper for notes. AOMs are, however, able to alter the virtual portion of their work station – their computer desktop. These alterations are often quite elaborate, ranging from the placement of key sources of information (such as weather radar, text based terminals, schedule visualization tools) to font size, coloring, and short-cut key combinations. Most AOMs observed for this study arranged their desktops to have not one, but two text-based terminals open at a time - even the AOMs who also had access to a schedule visualization tool. This, combined with the scratch paper, indicates that often AOMs are not able to hold all of the information they require in memory; instead they pull up critical information on one terminal and then use the second to pull up any additional information. It also suggests why AOMs often end up looking up information more than once. There is no good place to store information specific to individual problems. Instead the particulars of a problem must be kept in working memory until it is solved, is interrupted by a more urgent problem, or is put aside to wait for more information.

### *Design Insights*

The CWSS should organize all of the relevant information about a problem in a central location and in a way that supports the work structure of working on individual problems. Additionally, AOMs need to communicate with individuals both inside and outside of the AOCC. As the number of people inside the operations center becomes larger, it is harder to keep everyone within easy hearing, and sight distance. Consequently the CWSS must allow everyone to access relevant, up to date information about a problem to 1) foster coordination and 2) to allow communication to focus on solving problems without needing

to verbally repeat information.

#### **5.1.4 Sequence Model Analysis**

In accordance with the contextual design method, I examined the sequence models, (see Figures 27-34 in Chapter 4, for issues with intent, the user's approach, unnecessary steps and triggers.

##### *Intent*

The primary intent for all AOMs is to maintain the published schedule as closely as possible. In addition, any change to the work will need to account for several secondary intents. Maintaining a concise shift log is an important secondary intent. Other secondary intents were directly related to colleague relations. First, it was important for each AOM to resolve the problems without leaving a mess for the following shift and without creating unnecessary work for others. For example, shortening turn times was discouraged as a means of making up for a day because of the increased pressure it puts on gate agents, ground crews and baggage handlers.

##### *Unnecessary Steps*

The sequence models were examined for unnecessary steps. At many airlines there were very few unnecessary steps, but often many steps were repeated multiple times because an AOM was interrupted during the course of his work, or because she could not hold all of the information about a problem in her memory. Often these repeated steps happened while the AOM was collecting information about a specific problem. To address these issues the CWSS should assemble all of the pertinent information about a problem quickly and present in a common location. Additionally the CWSS should mark the place where the AOM left off in case of interruption, and should automatically save any open files.

##### *Triggers*

Across all airlines the most prominent trigger was a phone call from another person within the airline. The larger airlines also employed problem identification software which would

identify and classify potential problems. The smaller airlines instead used schedule visualization software which identified potential problems by altering the coloring scheme used to represent flights based on the issue detected; unfortunately this software requires the AOM to visually scan the schedule to monitor the state of the airline. Manually monitoring the schedule for potential problems does not lead to consistent results, especially when issues arise quickly while the AOM is not attuning to the monitoring task.

### *Paper and Paperless Systems*

In airline operations the use of paper versus electronic systems varied greatly by airline. Additionally, the use of automated systems themselves often varied with most airlines having developed specialized programs for very airline-specific purposes over the years. Most AOMs had access to special computer programs which were not accessible by individuals outside of the operations center, such as schedule database access. Consequently, information about problems or the shift log are compiled in a more accessible computer programs such as email systems and word processors which are separate from the computer systems in which the changes were originally made. This allows them to be widely disseminated. However the transcription causes additional work for the AOMs as they are forced to compile shift logs manually, which often resulting in tedious cutting and pasting of text from one program into another.

### *User's Approach*

It is apparent from the work model analysis that AOM's work practices vary between airlines. For example, AOMs at the larger airlines use the schedule problem identification software for problem identification instead of a schedule visualization tool. The work practices also vary between individuals, as each AOM will tackle the same problem in a slightly different way. For example, one AOM might prefer to talk with maintenance before talking to crew scheduling, whereas another AOM might prefer the opposite. In addition to both of these inter-airline and inter-AOM variations, work practice variation can also be attributed to intra-AOM variations. The intra-AOM variations are influenced by contextual features, such as time of day, available resources, number of concurrent tasks, physical proximity to

<b>Trigger:</b> AOM is notified of problem with aircraft/flight.	
<b>Intent:</b> Determine the availability of an alternative aircraft	Found a new aircraft for trip using the station schedule print outs
<b>Intent:</b> Find a new crew to solve problem.	Asked crew scheduling to find a new crew (knowing that it is likely an extra crew exists from daily briefings)
<b>Intent:</b> Prevent maintenance difficulties later	Called MOC to inform of plan
<b>Intent:</b> Alert ramp manager of equipment swap	Called the ramp manager
<b>Intent:</b> Advise interested individuals of equipment swap	Sent electronic message to explain changes

**Figure 38:** Sequence Model – Opportunistic

others, etc. For example, an AOM working the morning shift might be more inclined to swap out an aircraft to minimize a delay than that same AOM working the evening shift. Further an AOM who is working two different problems concurrently might be more inclined to deal with any additional cases which come in by simply delaying them (if appropriate) instead of trying to find a more elaborate solution. In this work, I argue that some of these contextually-based, intra-individual variations in work practice can be attributed to Hollnagel's CCMs, and pose a challenge to the design of a CWSS as three distinct work practices emerge from the analysis. For example, the same scenario of an AOM spotting a problem which could be solved by swapping aircraft might be addressed in three distinct ways by an AOM operating in different CCMs. The sequences are modeled in Figures 38, 39, and 40.

The proposed solution to this issue is to create a CWSS which has three distinct design modes supporting the three highest operational CCMs – Strategic, Tactical, and Opportunistic. The users should be free to select the CWSS modes as will best support their current operational CCM.



<b>Trigger:</b> AOM notices a problem on the station monitor.	
<b>Intent:</b> Verify that a crew was available before looking for an aircraft.	Asked crew scheduling if a new crew is available Crew scheduling found an available crew
<b>Intent:</b> Determine the availability of an alternative aircraft	Found a new aircraft for trip using the station schedule print outs
<b>Intent:</b> Verify that this swap will not cause maintenance difficulties	Called MOC to check validity of plan
<b>Intent:</b> Alert ramp manager of equipment swap	Called the ramp manager
<b>Intent:</b> Advise interested individuals of equipment swap	Sent electronic message to explain changes

**Figure 39:** Sequence Model – Tactical

<b>Trigger:</b> AOM notices a problem on the station monitor.	
<b>Intent:</b> Needed to verify that a crew was available before looking for an aircraft.	Asked crew scheduling for a new crew Crew scheduling found an available crew
<b>Intent:</b> Determine the availability of alternative aircraft	Found a few aircraft choices for trip using the station schedule print outs
<b>Intent:</b> Consult with maintenance	Called MOC to determine which aircraft would least impact the maintenance schedule
<b>Intent:</b> Consult with ramp manager about equipment swap	Informed the ramp manager of the swap, asked for any problems or modifications to swap
<b>Intent:</b> Advise interested individuals of equipment swap	Iterates as necessary with all individuals effected Sent electronic message to explain changes

**Figure 40:** Sequence Model – Strategic

### *Design Implications*

To account for the secondary intents identified above, the solution suggestion algorithms in the CWSS will need to respect minimum turn times and other time constraints such as not changing gates for departing flights within a certain time window. However, AOMs may need to override or vary these considerations in to match the circumstances.

The issue of paper versus paperless systems should be addressed by integrating the functionality of compiling and maintaining a shift log into the CWSS. The CWSS should record more information than is currently logged, such as the number, location and make of spare aircraft available over time. Additionally, the CWSS should compile many different types of reports from this information and send them as required.

One possible solution to issues with unnecessary steps is to provide all of the information relevant to a problem in a single window. Instead of requiring the AOM to look up information about the aircraft schedule, the pilot schedule, the crew schedule, the number of passengers scheduled, etc separately in a sequential manner, all of this information could be retrieved and presented simultaneously. Additional blank space should also be provided to accommodate additional information not normally retrieved, but which might be needed in specific situations.

The use of automation to detect potential problems is a good partial solution to the problem of making triggers more salient. The problem detection functionality should be integrated into the CWSS such that a potential problem can be converted into a problem file. The system should also incorporate an alerting system so that new high-priority cases can be brought to the attention of the AOM. Care must be taken however to allow the system to alert the user without becoming a distracting nuisance which interrupts the AOMs work too often. Similarly the CWSS should also give other airline employees the ability to log a problem into the system, as well as provide a mechanism for AOMs to enter a problem quickly into the CWSS as calls come in.

### 5.1.5 Process Fix Analysis

Examining all four work models at once with an eye to process fixes, I have identified two issues. The first is how the AOMs shift structure is organized. Presently, AOMs work shifts which start and end at the same time for all AOMs. This practice leaves the airline particularly vulnerable immediately following a shift change as no AOM presently working was actually working on the previous shift; consequently, an enormous burden is placed on the shift turn over report.

The second issue regards how the AOM's allocate work amongst themselves. At present the work is parsed along geographic lines, with each AOM taking responsibility for aircraft in their region when the problem is first discovered. Occasionally they will hand off cases if it is later found that the problem actually belongs to someone else, but often they simply work on the case themselves. While this organization makes conceptual sense, it does not take into consideration the levels of activity or the number of cases already assigned to each AOM. Considering that at present no mechanism exist to track the case load of each AOM and handing off cases is problematic this geographic parsing is currently necessary.

The CWSS should then enable cases to be entered by a larger number of individuals, such as gate agents, mechanics, or other OCC personnel. The cases could then either be assigned to AOMs either by a manager or automatically, or the AOMs could chose cases themselves from a central list of waiting cases. The paradigm of assigning cases to AOMs brings up some interesting questions in terms of allocation metrics. Possible metrics include AOM workload, AOM CCM, number of outstanding cases per AOM, geography, etc. It is tempting to assume that the number of outstanding cases per AOM will correspond directly with workload, but, as the complexity of each case can vary greatly, direct correspondence should not be assumed. The idea of assigning different AOMs different cases based on their operational CCM is a new idea that has not been studied, but has some merit as there may be performance advantages to allocating more cases to Strategic individuals before allocating additional cases to Opportunistic individuals.

These two process issues have lead to the identification of 2 ideas which are valid regardless of the AOM's CCM:

- Change static shifts to rolling shifts with 1-2 AOMs changing shifts every two hours
- Automatically logging reports to facilitate transition

### 5.1.6 Artifact Model Analysis

I examined the artifact models for issues with information inclusion, organization and presentation. The artifact models of most importance were the software artifacts, as the primary work of the AOMs was accomplished through computer systems. Most of the software tools were shown earlier in Figure 13.

#### *Information Inclusion, Organization and Presentation*

All of the airlines included in this study used a similar text-based terminal software provided by SABRE accessing the airline's master schedule database. This system can display a vast amount of information in text blocks. The information display changes based on what the user asked for and how the user asked for the information to be displayed. AOMs with 20+ years experience reading these text blocks are able to extract information very quickly. The most frequently requested information included:

- Flight information - what aircraft, flight and cabin crew are assigned to a specific flight
- Aircraft schedule - what flights are scheduled on a specific aircraft, overview of aircraft usage
- Crew schedule - what flights are scheduled for each crew member
- Passenger information - how many passengers are on an flight and how many are connecting
- Airport information - what facilities are available at a given airport
- Aircraft maintenance - when is an aircraft due back from maintenance
- Spare Aircraft - what aircraft of a certain type are available, when and where

Additionally, the smaller two airlines also had schedule visualization tools which organized the schedule information into Gantt charts by aircraft. The individual flights were then color coded, allowing the user to quickly detect any schedule deviations. However, this

software did not provide all of the information available from the text-based terminals, and so the two systems are often used in tandem.

The primary benefit of Gantt chart schedule representation is a representation allowing the AOM to the entire schedule quickly. As the number of aircraft at an airline grows, the benefits to such a representation are diminished.

Neither of these artifacts displayed all of the information relevant to addressing a problem in a single location. While the text-based terminal only allowed the AOM to look up one piece of information at a time, AOMs opened multiple screens so that they could see multiple pieces of information simultaneously. While the Gantt chart allowed the AOMs to see the full schedule, it was difficult to filter or sort and often required the AOM to visually scan the entire schedule searching for a specific flight.

The CWSS will need then to display all of the information frequently requested. The CWSS will automatically provide the relevant case information to the user. Importantly, the amount of information must be customizable through both filtering and sorting so that the AOMs can find the information that they need efficiently. While the text-based display of information in tabular form may not always be optimal, it does seem to allow a greater degree of customization than Gantt chart representation.

### **5.1.7 The Role of Automation in Airline Operations**

We can use the Information Flow Model, the Artifact Models and the Sequence Models together to analyze the current role of automation and identify new roles. Clearly the most common role automation has at present is an information repository for AOMs. Automation could also take on the role of information organizer or presenter, where the AOM can use the computer system to organize or present the information as she wishes. The final role that automation has assumed in airline operations is task execution assistant, whereby any changes to the airline schedule or gate assignment will be automatically entered into the official schedule and the effected individuals notified.

The roles that the automation does not take on which are most revealing. Presently the automation does not provide feedback about the implications of possible executed solutions.

**Table 4:** CWSS Function Description

Compare	Same as <i>Evaluate</i> for multiple solutions to compare
Complete	Completes a partially created solution by attempting to delay or swap follow on flights and balance fleet by suggesting cancellations
Consult	Sends the case to a colleague for evaluation and modification
Execute	Facilitates implementation of the solution
Evaluate	Evaluates solution along a number of different metrics
Modify	Modify any proposed solution and re-evaluate it
Suggest	Suggest solutions based on a constraints (Tactical) or an objective function of user's choosing (Strategic)

**Table 5:** CWSS Functionality by CCM

	Opportunistic	Tactical	Strategic
Execute	X	X	X
Evaluate	X	X	X
Compare		X	X
Complete	X	X	X**
Suggest		X*	X
Modify		X	X
Consult		X	X

\*Constraint specification

\*\*For modification purposes only

Nor does the automation compare competing solutions, or suggest solutions. At the larger airlines automation does play a small role of predicting potential problems. These conspicuous absences lead to the generation of roles which would be useful for the automation to assume in addition to the ones it already performs:

- Solution executor
- Solution analyst
- Solution generator
- Competing solution judge
- Problem forecaster

## 5.2 Functions and Roles

To succinctly summarize the design insights gleaned from the work models, the key functions that are required and the role of both the Human and the CWSS for each function in the redesigned work were identified. The explicit delineation of functions and roles for the work is not required by contextual design, but Beyer and Holtzblatt recognize the importance of

roles and use them as one lens through which to analyze work practices for inconsistency. As I am adding to the contextual design method by including three separate contextual control modes, the explicit delineation of roles for both the user and the CWSS for each CCM is especially useful. The required functions are defined in Table 4. Table 5 further distinguishes which functions are available in which design mode, and the roles are defined below:

**Alerter:** tries to draw attention to the system it is associated with  
**Authorizer:** authorizes the implementation of the action  
**Clerk:** copies and pastes data from one place to another  
**Compiler:** selects information to be used (usually from a pre-existing set)  
**Decision maker:** chooses between options implementer implements the action  
**Informer:** informs the necessary parties about an event  
**Interrogator:** questions either the human or computer agent judge determines action from criteria in the environment manager decides what to do with an action or how to modify a process  
**Mediator:** helps two or more agents agree on a course of action  
**Monitor:** monitors system for potentially problematic situations  
**Organizer:** organizes information in a useful format  
**Presenter:** presents information in a useful manner  
**Stenographer:** transcribes what they hear

Sheridan, Parasuraman and Wickens [79] problem solving behavior into four stages, which are useful when identifying the functions that a cognitive work support system would need to support. The areas are: information acquisition, coordination, analysis, and action. Tables 6 and 7 list the different roles for both the human operator and the CWSS for each of the functions. The tables are further divided into the different CCM design modes as the roles for the Human and CWSS may vary across modes.

### **5.3 Visioning**

The visioning process can be thought of as a “grounded brainstorm” because, although the ideas generated in a visioning process are not evaluated as they are generated, they are driven by the data captured in the work models. Starting points generated during the work redesign process are used to create a story about the new work practice. To capture the new vision for the work, an informed sketch of ideas is created, called a vision diagram. These stories describe the new work environment and technology. The resultant vision diagram shows what the work practice would be like if the current vision were adopted. A

**Table 6:** Work Functions and Role of User and CWSS

Functions	Opportunistic			Tactical		Strategic	
	Human	CWSS	Human	Human	CWSS	Human	CWSS
<b>Information Acquisition</b>							
Problem from phone call	stenographer	organizer	stenographer	stenographer	organizer	stenographer	organizer
Problem from conversation	stenographer	organizer	stenographer	stenographer	organizer	stenographer	organizer
Problem from computer program	manager, clerk	monitor, alerter, organizer	manager, clerk	manager, clerk	monitor, alerter, organizer	manager, clerk	monitor, alerter, organizer
Problem from instant message	manager, clerk	monitor, alerter, organizer	manager, clerk	manager, clerk	monitor, alerter, organizer	manager, clerk	monitor, alerter, organizer
Problem from CWSS	manager	monitor, alerter, organizer	manager	manager	monitor, alerter, organizer	manager	monitor, alerter, organizer
Weather monitor	manager, clerk	monitor, alerter	manager, clerk	manager, clerk	monitor, alerter	manager, clerk	monitor, alerter
<b>Coordination</b>							
Consult with colleagues face to face	informer	–	informer, interrogator, presenter, mediator	informer, interrogator, presenter, mediator	–	informer, interrogator, presenter, mediator	–
Consult with colleagues over phone	informer, interrogator	–	informer, interrogator, presenter, mediator	informer, interrogator, presenter, mediator	–	informer, interrogator, presenter, mediator	–
Send colleagues information electronically	authorizer, compiler	facilitator	authorizer, compiler	authorizer, compiler	facilitator	authorizer, compiler	facilitator
Receive response from colleagues electronically	authorizer, compiler	facilitator	authorizer, compiler	authorizer, compiler	facilitator	authorizer, compiler	facilitator



**Table 7: Work Functions and Role of User and CWSS**

Functions	Opportunistic			Tactical			Strategic	
	Human	CWSS	Human	Human	CWSS	Human	Human	CWSS
<b>Analysis</b>								
Evaluate	compiler, authorizer	analyzer, presenter	compiler, authorizer		analyzer, presenter, organizer	compiler, authorizer		analyzer, presenter, organizer
Double Check	compiler, authorizer	analyzer, presenter	compiler, authorizer		analyzer, presenter, organizer	compiler, authorizer		analyzer, presenter, organizer
Modify	–	–	–		–	manager, authorizer		organizer
CWSS Suggest	–	–	compiler, authorizer		creator, organizer, presenter	manager, authorizer		creator, organizer, presenter
Compare	–	–	compiler, authorizer		analyzer, presenter, organizer	manager, compiler, authorizer		analyzer, presenter, organizer
Human Suggest	creator	organizer, presenter	creator		organizer, presenter	creator		organizer, presenter
<b>Action</b>								
Execute	authorizer	informer, implementer	authorizer		informer, implementer	authorizer		informer, implementer
Choose	judge	organizer, presenter	decision maker		organizer, presenter	decision maker		organizer, presenter

vision diagram includes people and their specific roles, how they use technology, how they communicate with each other, and the technology. Vision diagrams are informal as they are just sketches of ideas for CWSS for AOMS:

- Create cases files for each problem
- Dynamically organize the AOMs by triaging problems
- Auto-generate shift transition reports
- Integrate phones into duty roster system

Usually only one vision diagram captures the new work process. Because of the large impact that the different CCMs have on the work practice, in this thesis three separate vision diagrams were created – one corresponding to each CCM. The following three subsections will describe each vision diagram in turn.

### **5.3.1 Opportunistic**

The vision diagram for the opportunistic CCM focuses on the AOM's interaction with the CWSS and the rest of their environment. In the opportunistic CCM the AOM work focuses on solving the current problem as quickly as possible. Often this means minimizing communication with others, searching for relevant information, and is focused on assessing the situation accurately and solving the problem quickly. The vision diagram is shown in Figure 41. The AOM is centered to illustrate that they are the individual of interest. Most of the arrows (which represent information and communication) are flowing in toward the AOM. In this mode I expect that the AOM will receive a lot of information in the form of alerts to problems and information about problems from a variety of sources, (often only one or a few sources for each problem) but that the AOM will not coordinate heavily with anyone.

The vision diagram shows two-way arrows between the AOM and the CWSS and the AOM and the “problem pad” because in the opportunistic CCM the CWSS is the primary source of information about any problem. The CWSS organizes the AOM's work using cases, where each case contains the information about any given problem. The CWSS will use a standardized problem/case entry system in the form of a paper pad (which can be read electronically by the computer). The AOM quickly fills out what information he knows about a problem on the case pad and a case is created in the CWSS and all relevant

information about the case is filled in. For example, if the AOM receives a call from a gate agent that the pilots found a problem with their aircraft for Flight 539 to Miami, the AOM would enter the data into the problem pad that the problem was with Flight 539. The CWSS would then automatically fill in the rest of the information in the case file that would be useful to the AOM regarding Flight 539, such as the aircraft number, flight crew information, cabin crew information, customer information, and next scheduled departure.

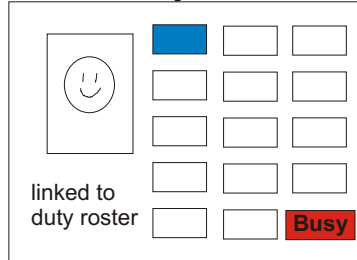
The phone system will be explained in more detail in the description of the strategic and tactical mode vision diagrams. In the opportunistic mode the important feature is the busy function which will automatically reroute calls to a free AOM or to the Duty Manager if all AOMs are presently engaged. This feature would allow AOMs to remove the disruption of further incoming problems when they are dealing with urgent matters.

A computer system is shown in the bottom right of the vision diagram. It is rather large part of the vision diagram because of its relative importance. The overall computer system contains additional programs to the CWSS as indicated on the vision diagram. Additionally, problems are contained in the CWSS. This list is also available to all of the AOMs and to the Duty Manager. The list can be sorted and filtered as well as categorized by priority, importance, severity and resolution time horizon. By making the list of outstanding cases available to everyone, the task of case assignment becomes much more flexible.

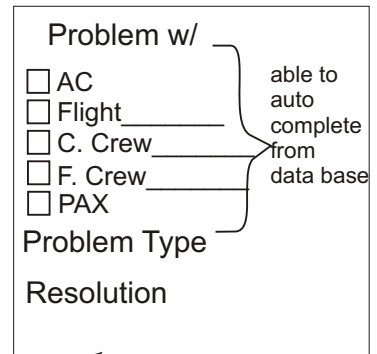
At the very bottom of the computer system is an area depicting the CWSS and its functionality. In the opportunistic mode the functions solution completion, solution test, and solution execution. Solution completion would aid the AOM in fully specifying the solution for delays, swaps and cancelations by making sure that delays and swaps are appropriately propagated and that the aircraft were balanced. For example, if a flight is delayed by 60 minutes, subsequent flights might also be impacted by that delay. The CWSS should aid the AOM in fully specifying the solution by helping them complete the solutions they specify. Solution test evaluates the solution along a number of different metrics such as # of passenger's disrupted, use of reserve aircraft or crew, etc., compares the solution evaluation to a predetermined set of minimums for each metric and highlights those metrics for which the solution does not meet the minimums. Solution execution facilitates the

# Opportunistic Vision

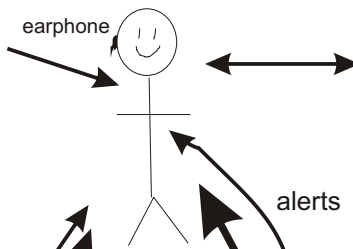
## Phone System



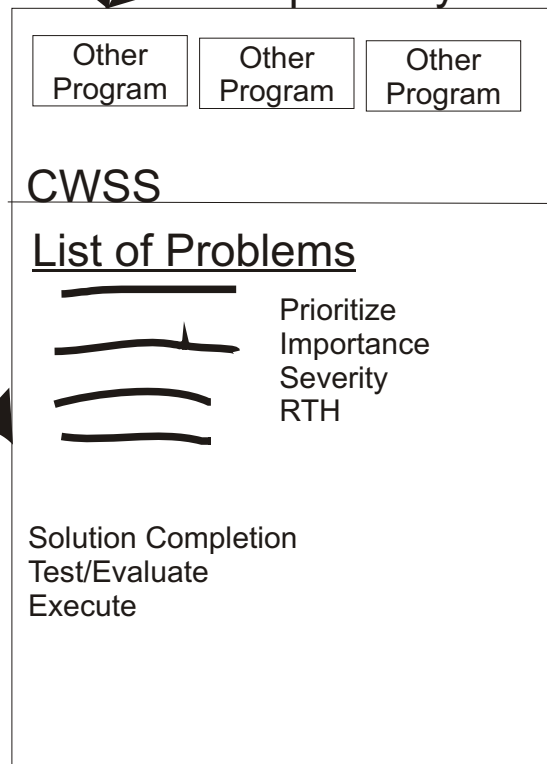
## CWSS Problem Pad



## AOM

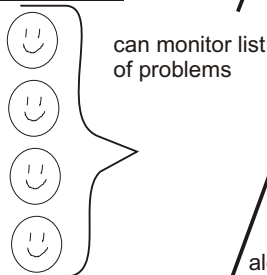


## Computer System



## Colleagues

### AOMs



## Others

ACS  
Duty Pilot  
Fleet Mgrs  
Crew Rep  
Duty Mgr  
Meteorology  
Attached  
Dispatchers

Centralized Database

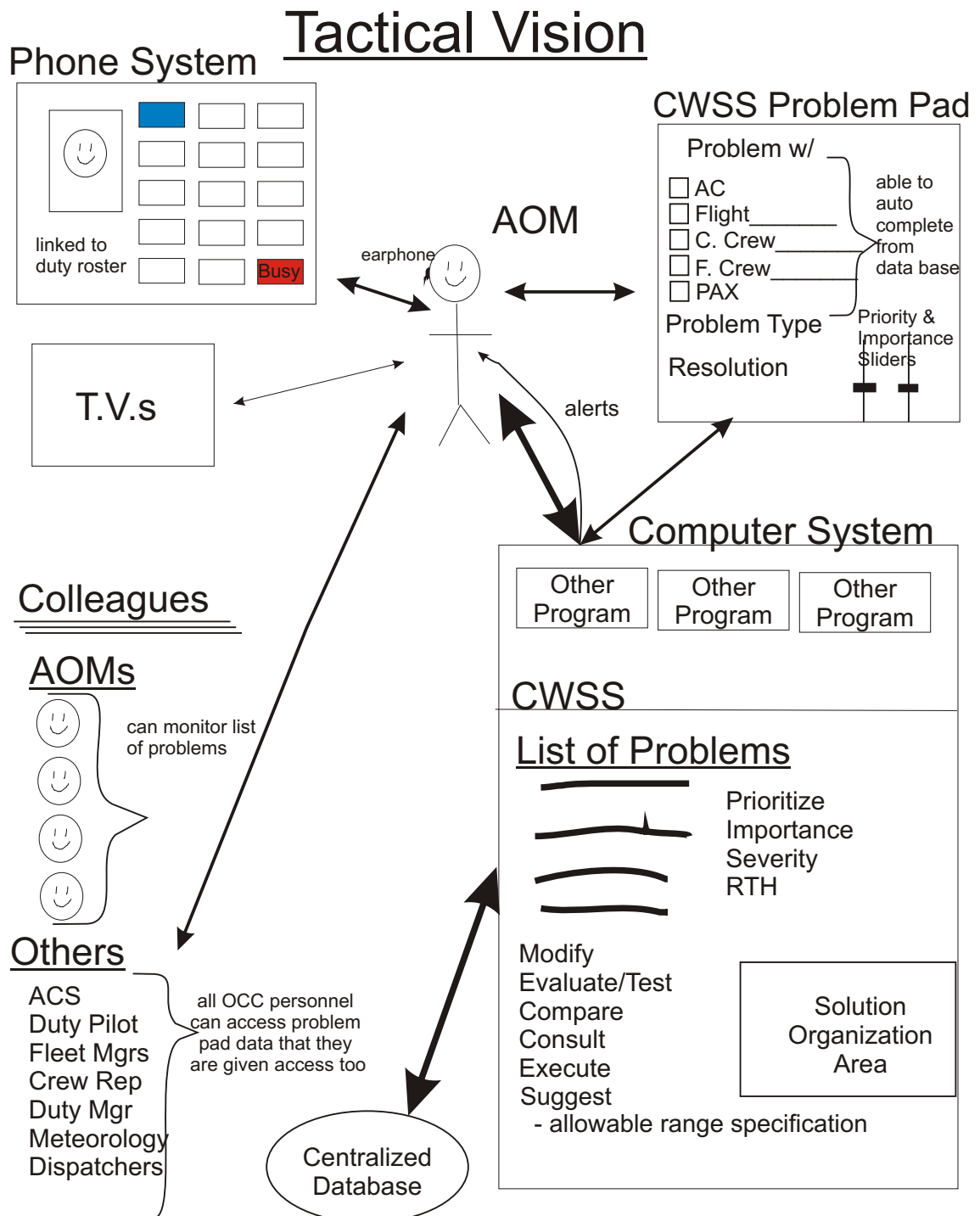
Figure 41: Opportunistic Mode Vision Diagram

implementation by posting changes to the official airline schedule and notifying all affected individuals.

### **5.3.2 Tactical**

The vision diagram for the tactical CCM has many similarities to the opportunistic vision diagram in that the main structural elements are the same; they both center on the AOM, organize the work by problem, contain a phone system, computer system, and a problem pad. The main differences are the amount of interaction the AOM has with the CWSS and with colleagues, and the complexity and capabilities of the CWSS including the problem pad. The vision diagram for the tactical CCM is expected to show interaction between the AOMs and his/her OCC colleagues. In addition to providing alerts to the AOM regarding possible problems with chosen solutions as in the opportunistic mode, the AOM will seek additional information in response to alerts provided by the CWSS by seeking the advice of her non-AOM colleagues; for example, if there is a problem with flight crew connections then the Duty Pilot will be consulted. Consequently, the vision diagram adds a narrow double headed arrow between non-AOM colleagues and the AOM. The consult function allows the AOM to send the problem off to another colleague to evaluate and make suggestions on.

As the CWSS will have expanded functionality the arrow representing the interaction between the AOM and the CWSS is bigger in the tactical mode than in the opportunistic mode. Similar to the opportunistic mode there is a heavy interaction between the AOM, problem pad, and computer system. Within the computer system the vision diagram indicates that the CWSS has taken on more functionality with a total of six distinct functions. In addition to those provided by in the opportunistic mode, the tactical mode has added a suggest function, a consult function and a solution compare function. The solution suggestion function will allow the AOM to specify a set of minimum criteria that he wishes the computer's solution suggestion will attempt to satisfy. Additionally, solution modification functionality is included, thereby allowing the AOM to modify any proposed solution and re-evaluate it. The solution compare function evaluates multiple solutions at once and compares the results.



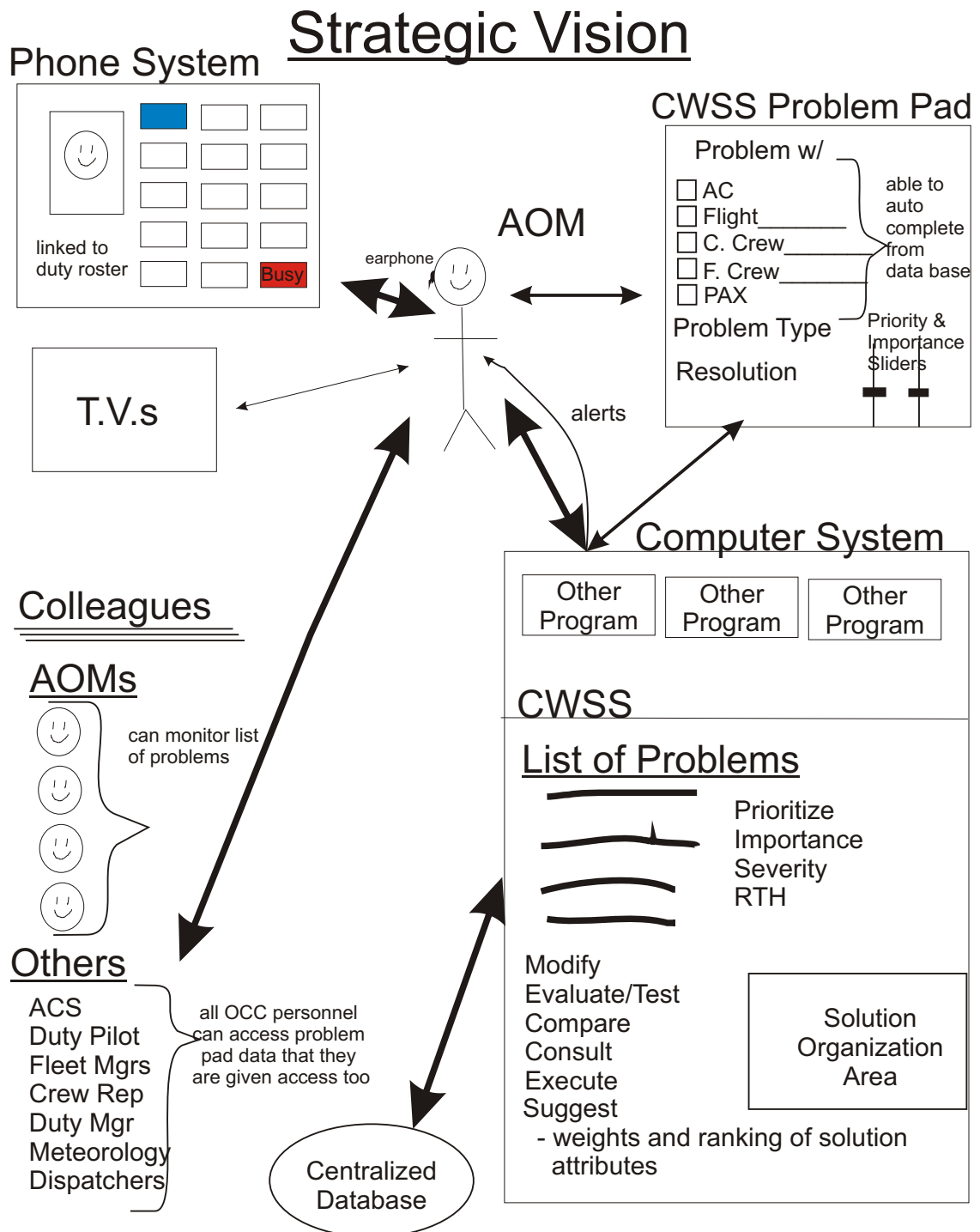
**Figure 42:** Tactical Mode Vision Diagram

As an AOM in the tactical mode is more likely to consult with his colleagues, he will make good use of the phone system. The phone system is located in the upper left hand corner of the vision diagram. The phone system will be linked into the duty roster so that if you call the station manager in Norfolk, the name and picture of the station manager on duty will appear. The inclusion of a picture in addition to just a name is to facilitate building personal relationships between employees, as facial recognition is more intuitive than name recall. While this functionality is not limited to the tactical mode, AOMs in the opportunistic mode are not expected to use it much so it is introduced in the tactical vision diagram.

### **5.3.3 Strategic**

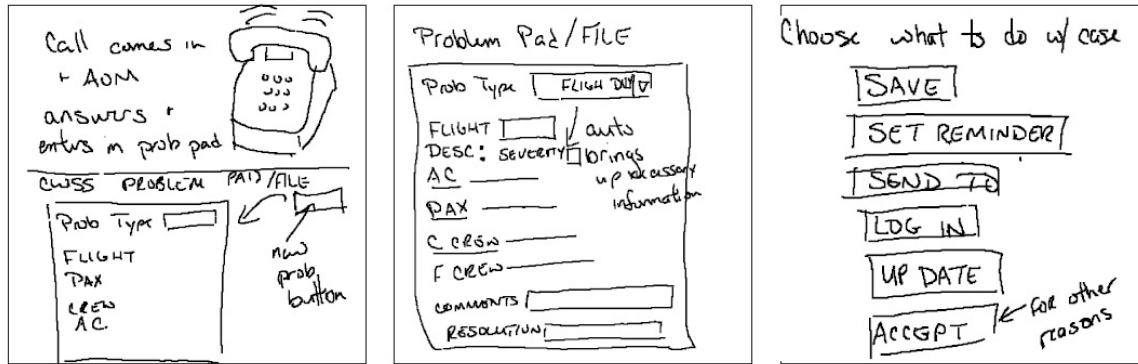
The primary differences between the strategic and tactical work practices is in the interaction between the AOM and his colleagues and between the AOM and the CWSS. The increased interaction between the AOM and her colleagues is represented by a thicker double headed arrow. In the strategic mode, as there is time for more collaboration and the opportunity to use more complicated solutions the amount of information seeking, communication, coordination and iteration will be greater than in other modes. The AOM might consult the Duty Pilot and Crew Representative multiple times while simultaneously iterating on a solution with the CWSS.

In the strategic mode the CWSS functionality is expanded to allow the AOM to take full advantage of all the information available, which might have proved over whelming in other CCMs. Additional functionality includes changes to the solution suggest function, and allows the AOM to ask the computer to suggest solutions using either a linear combination or a ranking of number standard objective functions. For example they may wish to find a solution which first minimized the number of missed connections for business class passengers and then minimizes the number of reserve crew used. The solution modification functionality will enable individuals operating in a strategic mode to ask for more complicated solutions and iterate multiple times before settling on a solution.



**Figure 43:** Strategic Mode Vision Diagram





**Figure 44:** Story Board: Information Acquisition via Phone Call

## 5.4 Storyboards

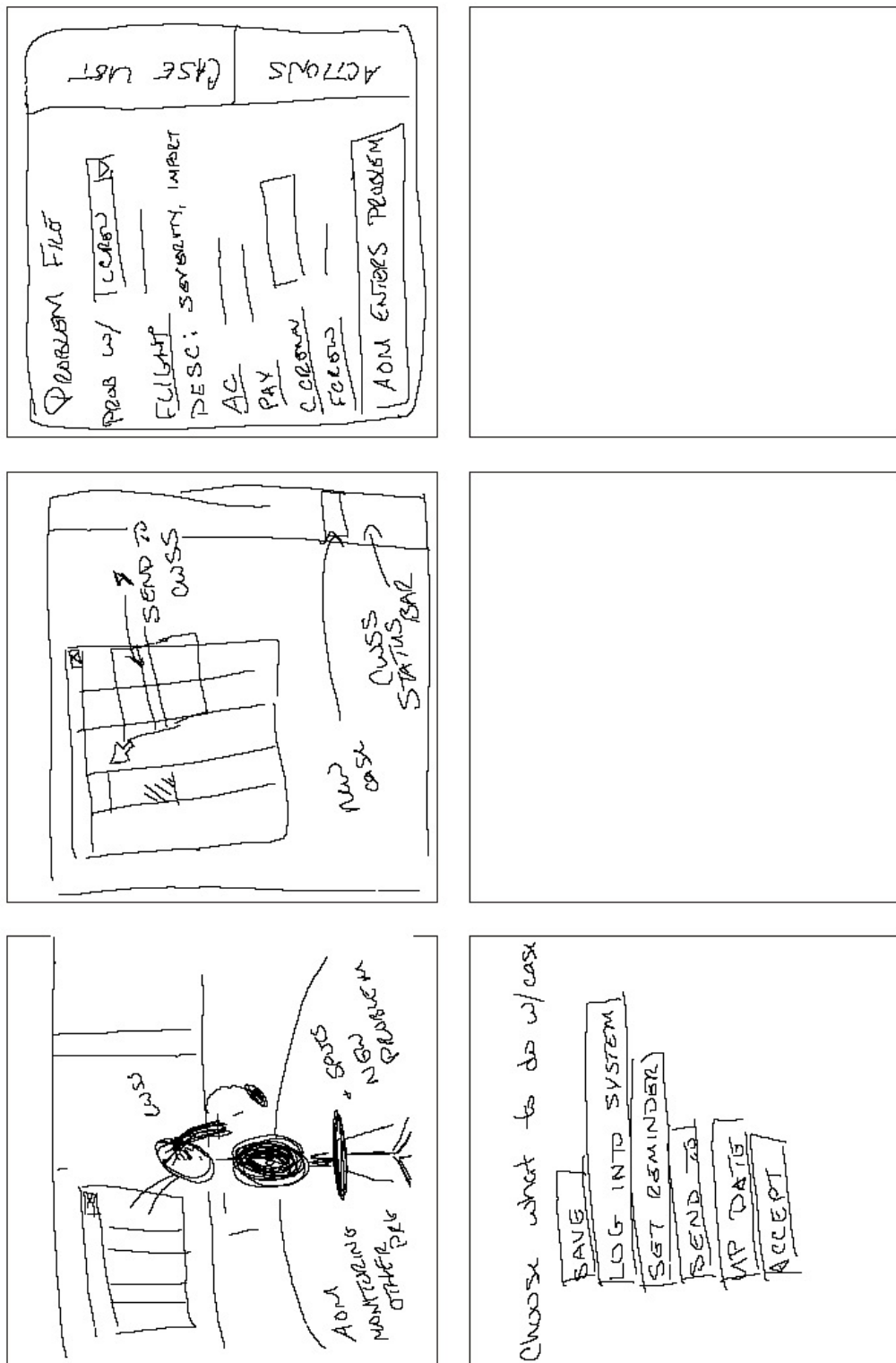
The vision diagrams discussed previously capture the new vision as a single picture without specifying the temporal sequence, i.e. how the work will be done. The contextual design process uses storyboards to specify how the work unfolds over time. Storyboards capture the new work sequence in pictorial form with each frame capturing a single scene. Storyboards can show individuals interacting with other individuals, artifacts, or screen shots of artifacts (in our case the CWSS), and may list actions being taken by the artifact itself. The storyboard may show aspects of user interface (UI); however, at this stage any UI shown is representative only of the UIs functions.

Story boards are created to flesh out the new work practices presented in the vision diagrams. They depict the majority of functions identified in Tables 6 and 7. Figures 44-47 contain storyboards which depict how the AOMs enter information into the CWSS from a number of common sources. While the frequency of the different sources will vary depending on CCM (with other's advising the AOM of potential problems being more common during the opportunistic mode and with the AOM themselves identifying problems through the use of the CWSS or other software alerting system), I expect to see most of the functions used in all of the modes. The sequence of actions envisioned are variants of the following:

1. AOM notices problem or has attention drawn to problem
2. AOM opens a window to quickly jot down the basic facts of the problem
3. AOM submits problem or send problem to appropriate individual



Figure 45: Story Board: Information Acquisition via Colleague



**Figure 46:** Story Board: Information Acquisition via Computer System other than CWSS



**Figure 47:** Story Board: Information Acquisition via Instant Messaging

Clearly the more highly integrated the CWSS is with all the other software tools which monitor the airline operations, the easier this process might be. For example, if the AOM usually monitors the airline schedule using a schedule visualization tool and notices a problem with a particular flight or a particular aircraft, then they can click on the flight and “send” it to the CWSS where a case will be automatically opened. Because different airlines use different tools to monitor their schedules I have restricted the CWSS design to the creation of problem cases manually; a similar or even more integrated capability may be possible for airlines that currently use a problem alerting tool.

Figures 48 and 49 contain storyboards which depict how the AOMs can coordinate with each other. In the storyboards, the AOM who wishes to initiate coordination simply sends the case for consultation to another individual within the OCC – or any colleague with access to the CWSS tool. The consultation request will alert the AOM’s colleague of a pending request and make the problem case, possible solutions and analysis available. Additionally, Figure 49 shows that, ideally, the phone system would be linked to the CWSS application and would enable simplified phone communications by automatically listing the individuals to whom the consultation request was sent.

Figures 50 and 51 contain storyboards which depict how the AOMs can use the CWSS to create new solutions for their current problem in different CCMs. In both cases the sequence follows the following pattern:

1. From the case description window the AOM sets the parameters for the computer suggest function, which takes the AOM to a separate window
2. In the new window the AOM can set the parameters by which the computer will optimize a solution
  - In the tactical CCM the AOM can chose which metrics to maximize or minimize – each metric will correspond to a generated solution. Additionally, the AOM can specify the acceptable range of each metric when optimizing others– if one exists.
  - In the strategic CCM the AOM can choose between ranking the metrics to weight each metric. The computer will then use this input to generate an optimal

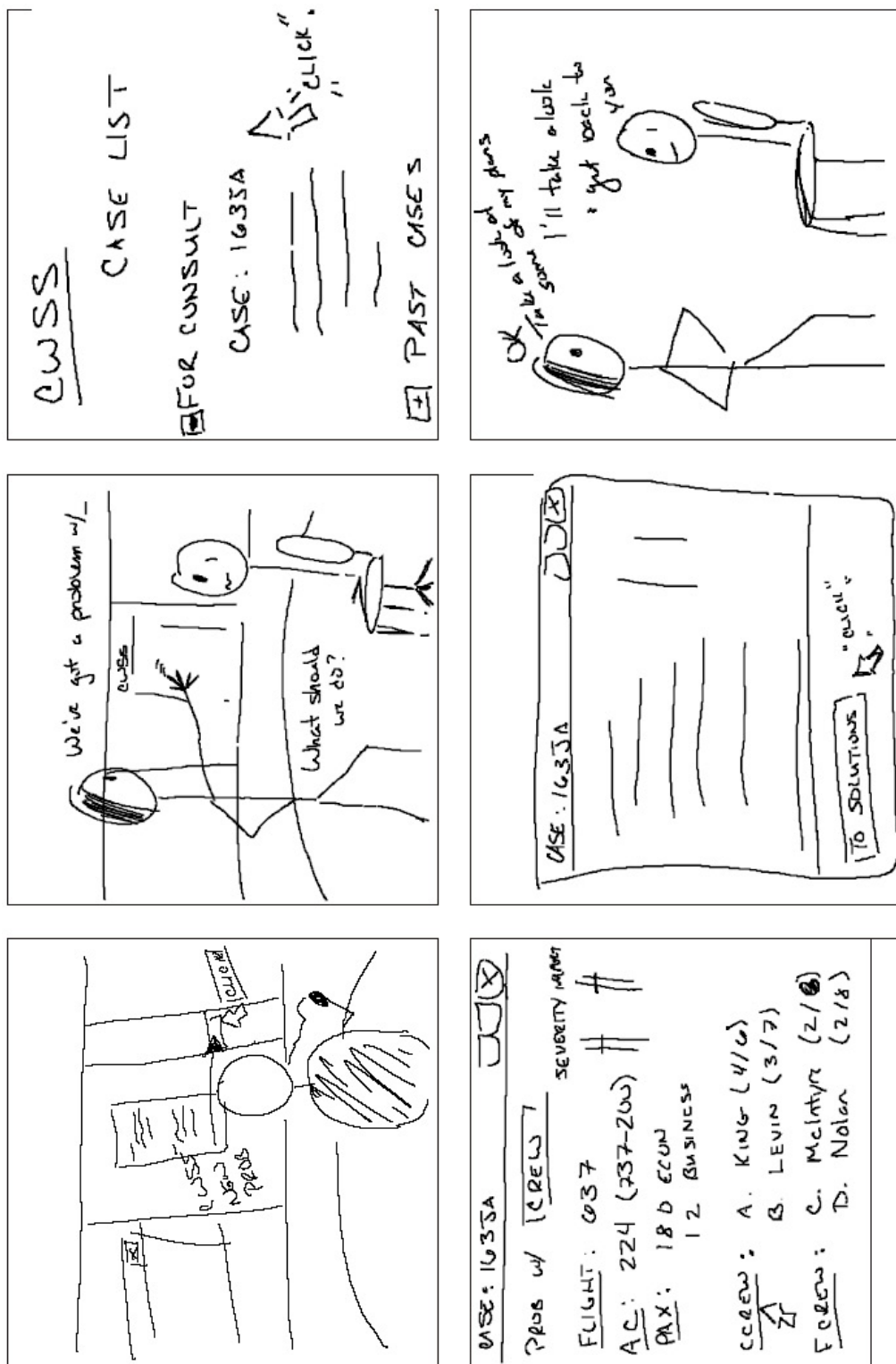


Figure 48: Story Board: Coordination with Colleagues Face to Face



Figure 49: Story Board: Coordination with Colleagues via Phone

CASE # 0753A						<input checked="" type="checkbox"/>
CASE VIEW ACTION						
Plan: MOPD						
- DELAY						
526 00:30						
155 00:40						
+ CANCEL						
+ SWAP AC						
+ CREW						
Evaluate	Double Click	Problem <del>Open</del>	Suggest	Consult	Execute	

CASE# 07531 CASE VIEW ACTION Solutions	071411 07000 Alpha <input type="checkbox"/> MORD <input checked="" type="checkbox"/> MISAC <input type="checkbox"/> MSCF	PROB W/ <u>CEEW</u> 1	FLIGHT: 0037 AC: 224 (737-200) PAIR: 180 ECUJ 1Z BUSINESS	SECURITY MAPS # #	CCEW: A. KING (414) B. LEVIN (3/7) FEDEW: C. McIntyre (2/6) D. Nolan (2/8)	Double Check	Compare Suggest	Consent Execute
		Evaluate						

CASE# 0753A CASE VIEWS ACTION	Solutions <input type="checkbox"/> IT/Inf <input type="checkbox"/> Bus <input type="checkbox"/> Alpha	Double <input checked="" type="checkbox"/>	Quick <input type="checkbox"/>	Compare <input type="checkbox"/>	Summary <input checked="" type="checkbox"/>	Consult <input type="checkbox"/>	Execute <input type="checkbox"/>
		PPOS w/ CREW 1 SECURITY MATH FLIGHT: 037 AC: 224 (337-200) PAIR: 180 ECOW 1Z BUSINESS CREW: A. KING (4/6) B. LEVIN (3/7) FEREW: C. McIntyre (2/6) D. Nolan (2/8)					

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Figure 51: Story Board: Analysis using CWSS to Suggest Solution (Strategic)

solution according to that combination.

3. AOM chooses the suggest function, and the computer will generate either one or multiple different solutions depending on the suggestion settings. Note: If the suggest settings have been previously set, and no changes are required, Step 2. can be omitted

Once new solutions are created, they appear on the list of solutions differentiated from solutions created manually by the AOM. From the problem overview window, the individual solutions can be examined by clicking on one of the solutions, thereby opening a solution window which describes the plan of action. Although the pattern described above is similar for the tactical and strategic CCMs, AOMs in the strategic mode are likely to loop through the sequence of events more than AOMs in the tactical mode, as they coordinate with colleagues and compare solution alternatives.

Figure 52 contains the storyboard describing how an AOM would analyze a solution in the opportunistic CCM. In the opportunistic mode, the CWSS will automatically suggest a default solution, i.e. the solution that delays where necessary and balances the fleet. The AOM may alternatively choose to create his/her own solution and have it evaluated. From the case viewer window the AOM chooses the evaluation function which opens a new window containing the solution evaluation data. In the opportunistic case this data is organized via a spider graph, with the individual axes descriptors leading to more in depth data analysis. For other CCMs a spider graph may not be practical, especially where multiple solutions are being compared, and consequently other display options such as bar charts and interactive tables will be used.

Figure 53 contains the storyboard describing how an AOM would double check a solution in the opportunistic CCM. From the case viewer window the AOM chooses the double check function which opens a window containing the solution evaluation data, similar in presentation to the evaluation function presentation. However, instead of showing the absolute values of the solution along different metric lines, the value relative to a pre-established set of minimums (or maximums depending on the metric). While many solutions may meet these minimums, it is important to make sure that the minimums are maintained. Once the solution has been double checked the AOM can confidently choose to execute the

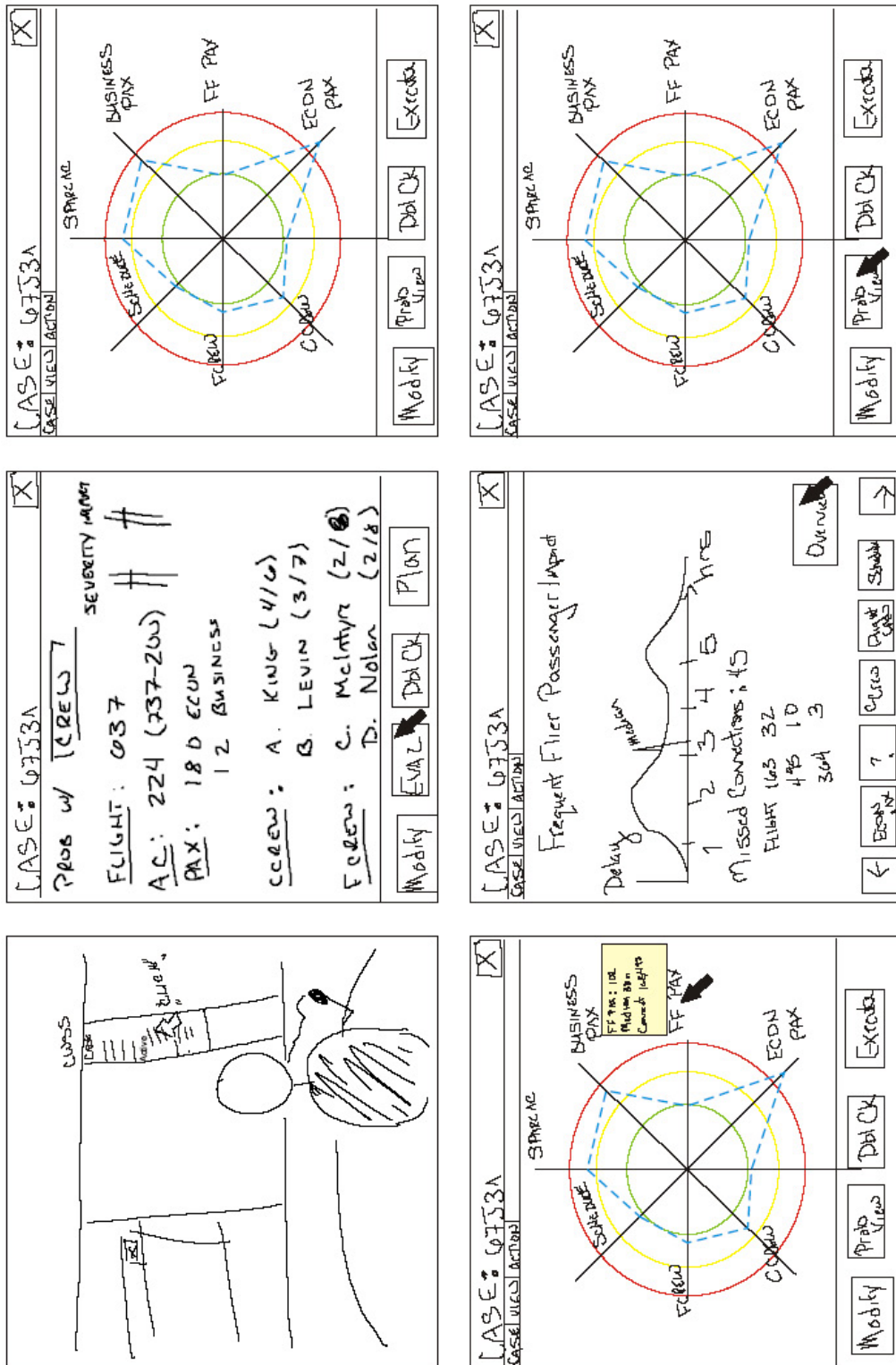


Figure 52: Story Board: Analysis to Evaluate Solution (Opportunistic)

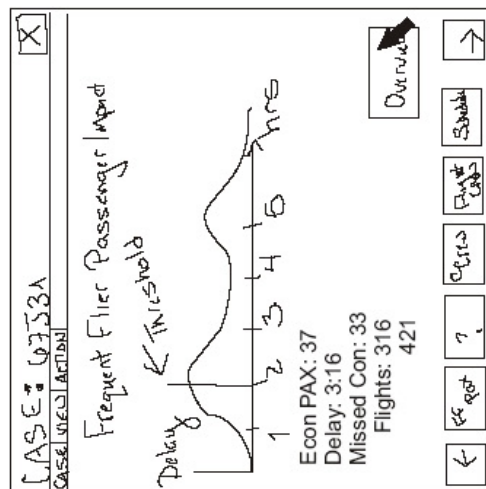
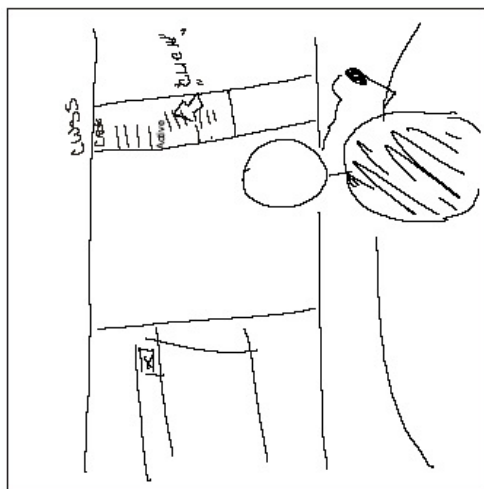
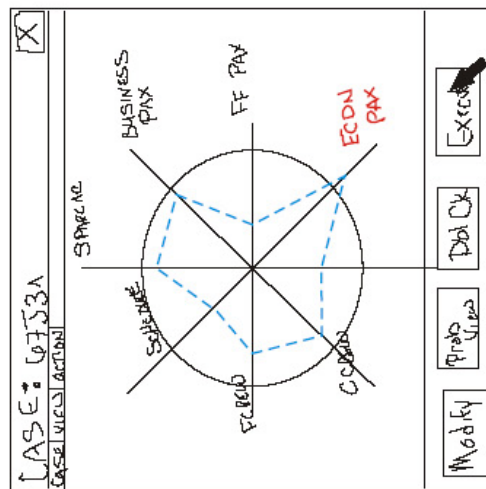
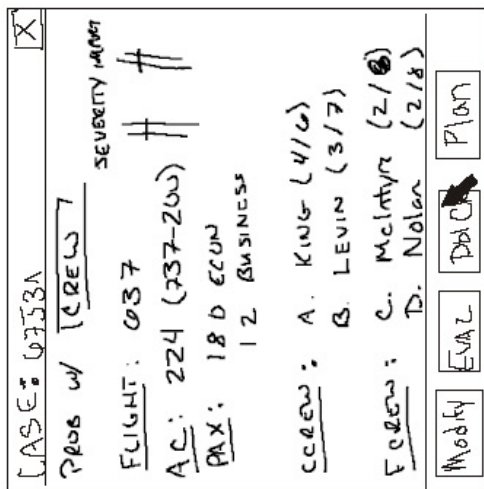
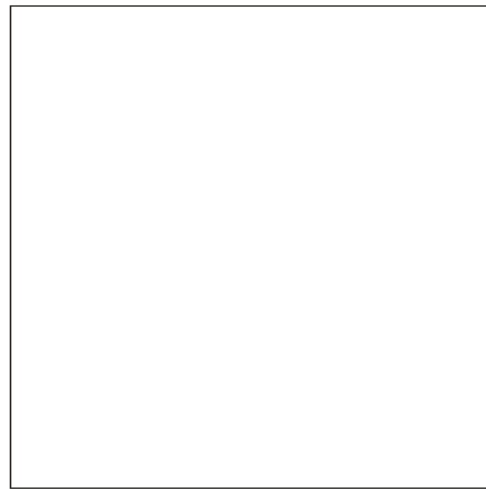
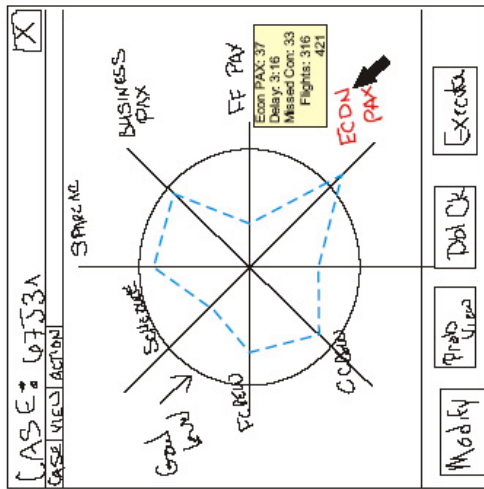


Figure 53: Story Board: Analysis to Double Check Solution (Opportunistic)

proposed solution.

### **5.5 Summary**

The work redesign process has led to the development of three complementary vision diagrams, each corresponding to a specific CCM. The vision diagrams illustrates the variation between CCMs in expected in the information acquisition, collaboration and consultation of colleagues, and solution iteration with more being expected in the strategic CCM. Additionally the vision diagrams introduced some of the desired CWSS functionality, summarized in Tables 4 and 5.

The vision diagrams were then supplemented by the development of a series of storyboards which provided a temporal dimension to the new work flow not captured in the vision diagrams. The new work flow centers around individual problems or cases. The problems can be added into the system either manually or automatically. Once in the system, the cases can be worked on by an AOM and, if necessary, passed off for consultation. The CWSS can to aid with solution generation, completion, analysis, comparison and execution. The storyboards also illustrated how these functions might take on different forms to better support each CCM.

## CHAPTER VI

### COGNITIVE WORK SUPPORT SYSTEM - PROTOTYPE DESIGN

The fourth step in Contextual Design is system design, which creates a User Environment Diagram (UED) and the prototype. The UED applies the vision diagrams and story boards and creates to create a structure with the necessary functionality and supporting a natural flow of work. Prototype creation implements the UED's structure and functions to iteratively evaluate and refine the design. This chapter contains describes the creation of the UED and of a prototype with sufficient functionality to examine the design of a CWSS supporting a range of CCM.

#### ***6.1 User Environment Design***

The user environment design represents key aspects of the system design that users interact with, the aspects of the work that it supports, and how the the system relate to each other. The user environment design focuses on system structure and functioning are specifying the forming of the interface (e.g. font, icons, etc) does not include user interface (UI) details. The UED highlights the *focus areas* around which the software should be designed. Each focus area can be described by a single purpose statement and provides a coherent set of functions supporting an important activity. Thus the selection of focus areas defines the flow of work when interacting with the system.

Focus areas are connected via single and double links. Single links represent transitions between activities, double links represent when the user needs to do the work of one focus area in the context of another, e.g. a spell checker which hovers over the primary focus area. Focus area can contain as useful to guide design, the purpose of the focus area, the functions contained in the focus area, identified by those invoked by the user and those invoked by the system, function clusters, links, work objects, constraints and issues. Function clusters are groups of functions which are grouped together and are given an single identifier for clarity. Work objects are things that the users sees and manipulates in the focus area. Constraints

include any implementation constraints such as speed, reliability, availability, form factor, etc.

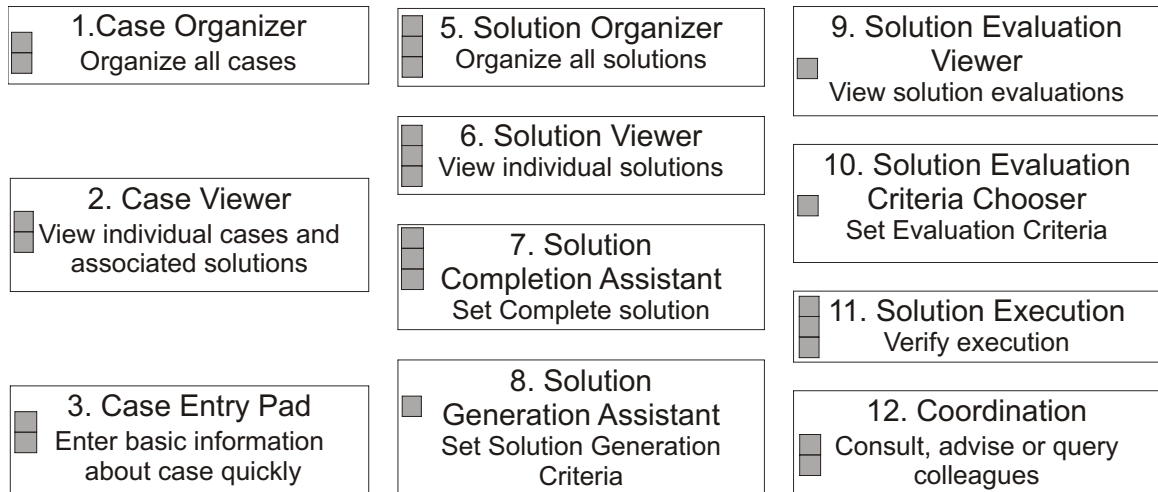
### **6.1.1 Focus Area Identification**

The first step determines the Focus Areas required from the functionality revealed in the Vision Diagrams. Specifically, the functions of computer assistance with solution completion and solution generation leads to the Solution Completion Assistant and the Solution Generation Assistant focus areas. The functions of solution evaluation and solution comparison leads to the focus area of Solution Evaluation Viewer and the Solution Evaluation Criteria Chooser, and the Solution Viewer and the Solution Organizer to view individual solutions and to organize multiple solutions. Finally, the function of facilitating the implementation of these solutions leads to the Solution Execution focus area.

Additional focus areas are created to support other insights derived from inspecting the work models. Specifically recognizing that the work was primarily “problem” driven leads to the need for three focus areas: The Case Viewer to view all of the information associated with a specific problem; the Case Organizer to sort and filter multiple cases that an AOM might be handling over the course of a day; and the Case Entry Pad to quickly assemble a case from minimal pieces of information. Additionally, the insight that communication and coordination played an important role resulted in the Coordination Focus area.

To summarize, there are eleven focus areas as listed below. Each one is described in detail in the following sections.

1. Case Organizer
2. Case Viewer
3. Case Entry Pad
4. Schedule Viewer
5. Solution Organizer
6. Solution Viewer
7. Solution Completion Assistant
8. Solution Generation Assistant
9. Solution Evaluation Viewer
10. Solution Evaluation Criteria Chooser
11. Solution Execution
12. Coordination



**Figure 54:** CWSS Focus Areas

The Focus Areas need to support each CCM use variants of this list of Focus Areas. In some cases the Focus Areas required might be the same across CCMs, but the form that their particulars might need to be tailored to each. For example, all CCMs required some sort of solution evaluation capability; however the extent of that capability varies with CCM. An opportunistic CCM would merit only a rudimentary evaluation, whereas a strategic CCM would merit an extensive evaluation. These variations are demarcated by small boxes located inside of the Focus Areas. If only one box is present it indicates that a Focus Area has a special form specifically designed to support only one the CCM represented. If a Focus Area has two boxes, then the Focus Area shares a single form the two CCMs shown and has a different form for the CCM not indicated. If the Focus Area has three boxes then it has a single form appropriate for all three CCMs. The focus areas are shown in Figure 54.

### 6.1.2 Focus Area Integration

Next, links were created between Focus Areas to support the work flow captured in the storyboards. Single links transition the user from one focus area to another. Double links illustrate when the user needs to do the work of one focus area in the context of another; examples of these double links can be seen in most spell check features which pop-up a



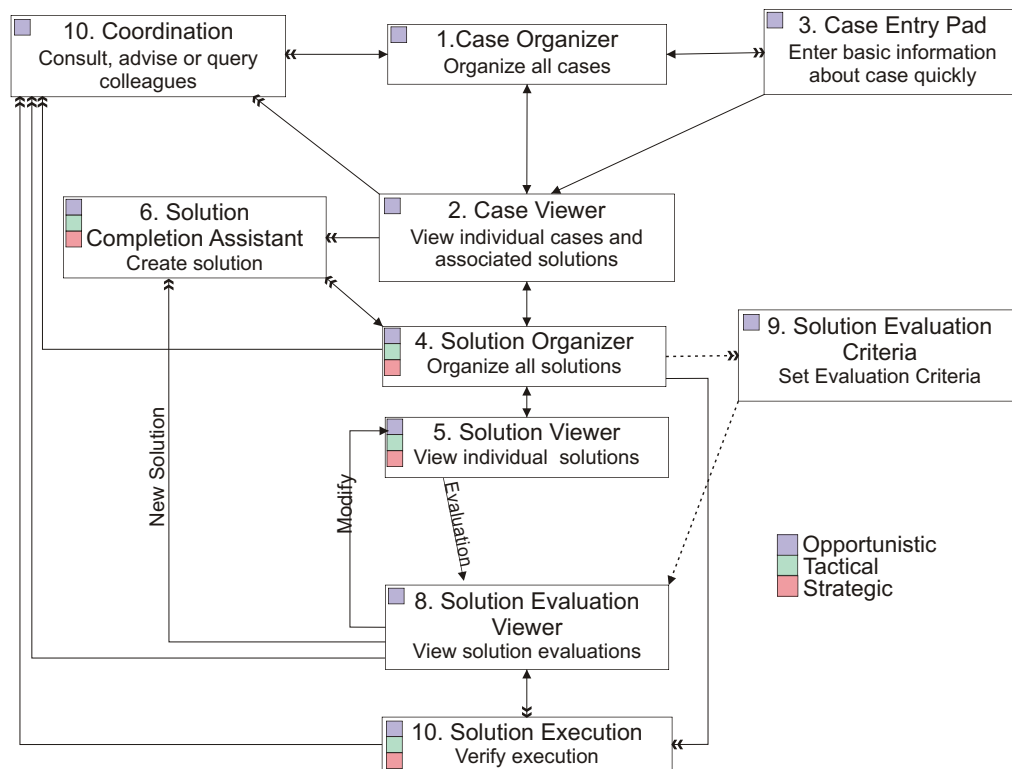
small spell check focus area on top of the current focus area. In this thesis, single inks are represented with single headed arrows, and double links are represented by double headed arrows.

Based on the Storyboards the main CWSS consists of five focus areas: Case Organizer, Case Viewer, Solution Organizer, Solution Viewer and the Solution Evaluation Viewer. The other focus areas are accessed as needed through double links. Based on the functionality specifications from the Vision Diagrams, the Solution Generation Assistant focus area is not available in the opportunistic mode because computer generated solutions are too time consuming given the multiple iterations needed to fully develop and understand them. The rest of the links were generated by stepping through the story boards and determining focus area transitions which support the new work flow. A separate UED was created for each CCM for clarity. These UEDs are shown in Figures 55 through 57.

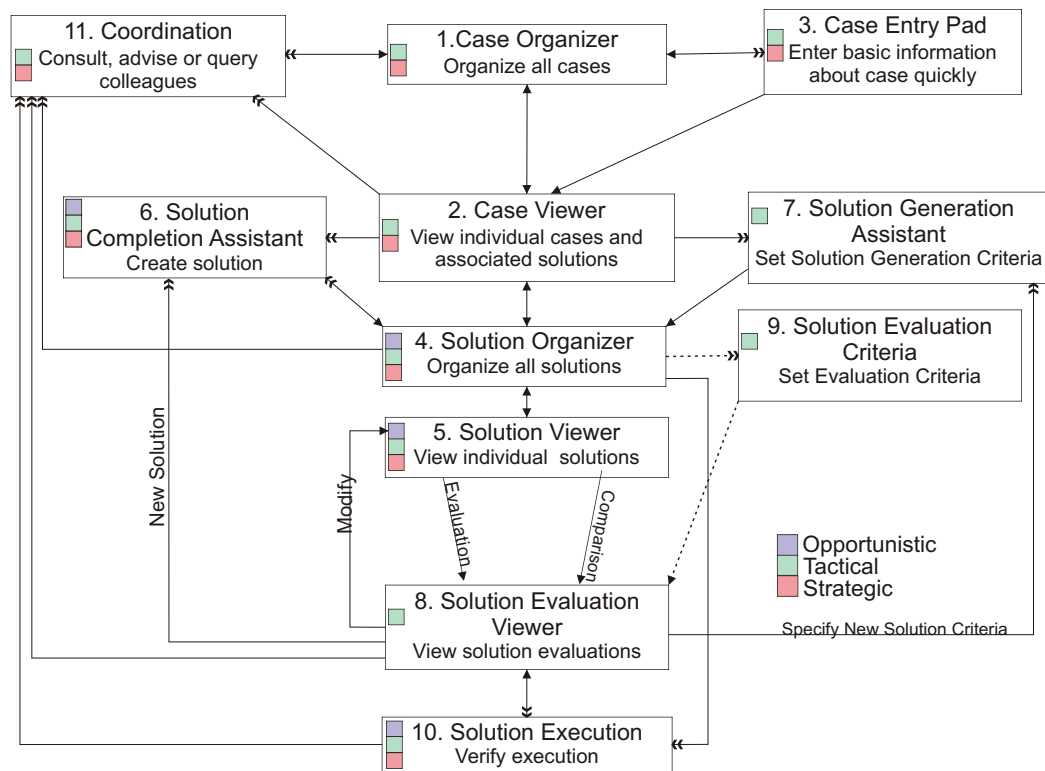
In the opportunistic CCM, the work will follow a linear flow with the AOMs proposing a single solution based on their experience, possibly asking for the CWSS to help complete the solution from a simple specification. Once a solution has been generated, the AOM can evaluate the solution to verify that it meets specific minimum criteria. If the solution does not, the AOM will then iterate by modifying the solution and evaluating it again. Once he/she is happy with the solution, the AOM will execute the solution.

In the tactical CCM, the AOMs will seek to iteratively improve the solution to meet minimum conditions or multiple criteria. In the tactical CCM therefore the CWSS will provide a Solution Generation Assistant in addition to the Solution Completion Assistant. The AOM in the tactical mode may wish to generate multiple solutions and to compare them, so a comparison function will be included as a link between the Solution Viewer and the Solution Evaluation Viewer. In this mode, the AOM may also need to iterate on the solution by either directly specifying a new solution or modifying an existing solution. Additionally, the AOM may wish to generate additional solutions using different criteria. Once an acceptable solution has been found, the AOM will execute the solution.

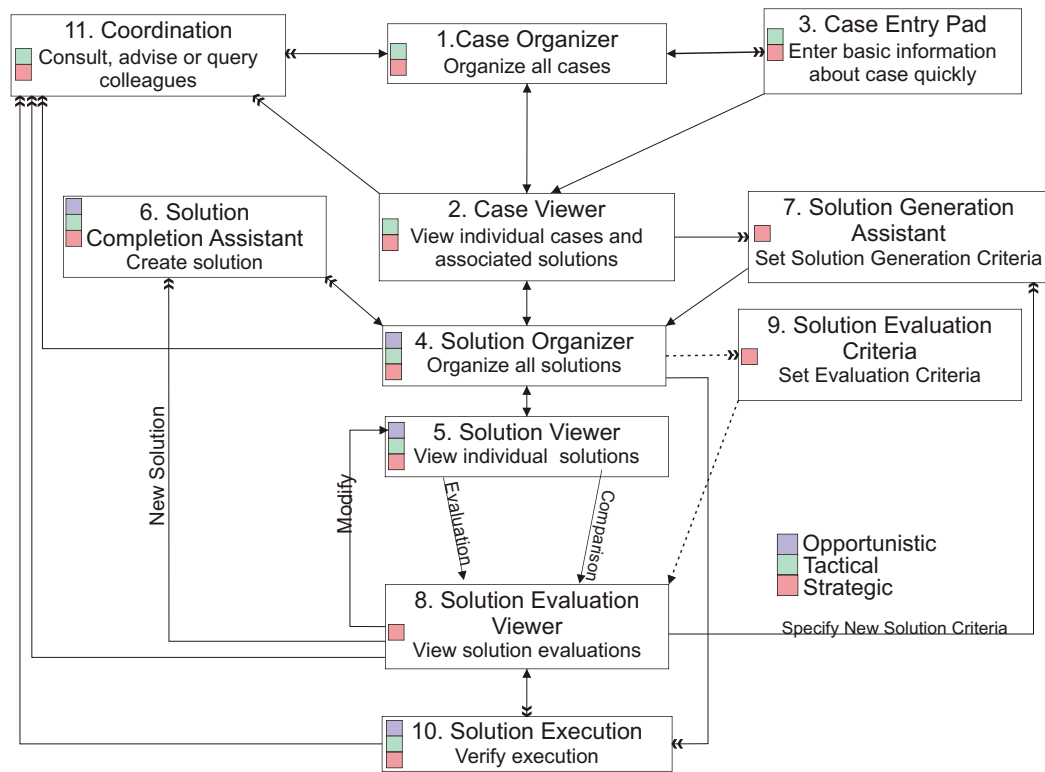
In the strategic CCM, the AOMs will seek to find an optimal solution. In the strategic CCM the double link between the Case Viewer and the Solution Completion Assistant will



**Figure 55:** Simplified UED: Opportunistic



**Figure 56:** Simplified UED: Tactical



**Figure 57:** Simplified UED: Strategic

be removed, reserving access to this focus area for solution modification only. Similar to the tactical mode, an AOM in a strategic CCM will wish to generate multiple solutions and to compare them, so the comparison function added to the tactical UED will also be included in the strategic UED. In this mode, the AOM can iterate on the solution by either directly by modifying an existing solution or by generating additional solutions using different criteria. Once an acceptable solution has been found, the AOM will execute the solution.

### 6.1.3 User Environment Design Walkthrough

After the creation of the UEDs, I conducted a series of user environment design walkthroughs, where 1) the structure of the UEDs was checked for coherence with the proposed work flow; 2) the focus areas were checked that they are distinct from each other, and

support all the necessary work; and 3) the links were examined relative to the work flow. During this walkthrough, test cases were developed to determine if the UEDs were able to facilitate tasks likely to be encountered by AOMs. Examples included flight problems, aircraft problems, station problems and ground delay programs (GDPs).

During this process several focus areas that were found to be missing. Consequently, three new focus areas were created: 1) Schedule Viewer focus area where the whole airline's schedule could be displayed, sorted and filtered; 2) GDP Viewer focus area where any aircraft included in ground delay programs could be displayed, sorted and filtered; and 3) the Spare Aircraft focus area where spare aircraft could be organized and their location and availability displayed.

In summary, at the end of the user environment design process the focus areas included:

1. Case Organizer
2. Case Viewer
3. Case Entry Pad
4. Schedule Viewer
5. Solution Organizer
6. Solution Viewer
7. Solution Completion Assistant
8. Solution Generation Assistant
9. Solution Evaluation Viewer
10. Solution Evaluation Criteria Chooser
11. Coordination
12. Schedule Viewer
13. GDP Viewer
14. Spare Aircraft Organizer

#### **6.1.4 Focus Area Descriptions**

##### *Case Organizer*

The case organizer focus area organizes the cases entered in the CWSS and allows the user to sort and filter the cases such as highlighting unresolved versus resolved cases, and sorting cases based on which are under the user's control versus those under the control of another AOM, time entered into the system, time left until action must be taken, or user specified priority. Additionally this focus area provides the functions to select cases for further processing such as solution creation.

### *Case Viewer*

The case viewer focus area displays all of the information about a case in a single location. The information in the case viewer is populated automatically from partial information entered into the Case Entry Pad (e.g. from entry of a flight, aircraft or station indicate all aspects of operation which correspond). In this focus area the user can modify the information about a case and add notes. Information included in this focus area includes: the affected flights, subsequent flights at that aircraft or station, passenger information for affected flights, expected problem duration, problem priority, problem cause, who is responsible for the problem, and the problem type. Problems are categorized into three distinct types: Flight, Aircraft, or Station Flight problems potentially affect only a single flight; Aircraft problems affect a single aircraft (or multiple flights); Station problems affect a single station (potentially involving multiple aircraft and flights).

### *Case Entry Pad*

The case entry pad focus area allows information about a new case to be easily and quickly entered into the CWSS. The case entry pad focus area contains only the most germane information about a case. With partial information entered here the CWSS is able to fully populate the case viewer focus area automatically from the underlying database.

### *Solution Organizer*

The solution organizer focus area organizes the solutions for a specific case and allows the user to sort and highlight the cases based on the solution components: cancelations, delays, equipment swaps, new flights and ground delay program (GDP) slot swaps. Additionally, it serves as a mechanism to select solutions for further processing such as solution modification, evaluation or comparison.

### *Solution Viewer*

The solution viewer focus area displays all of the information about a solution, by listing out the individual solution components.

### *Solution Completion Assistant*

The solution completion assistant focus area allows the AOM to begin a solution and then request that the system “complete” the solution by filling in all other actions required to regain a balanced schedule. For example, the AOM may wish to delay a flight by 60 minutes, causing delays in subsequent flights assigned to that aircraft. In this case the CWSS would determine which, if any, subsequent flights might be affected and allows the user to from several scheduling modifications. For cancelations, the system attempts to balance the aircraft by suggesting possible additional cancelations which position subsequent aircraft properly. For equipment swaps, the system will propagate the swap for the subsequent flights so that all of the flights are assigned to the correct aircraft. The solution completion assistant focus area has no ability to generate solutions from scratch, but can complete partial solutions initiated by the AOM.

### *Solution Generation Assistant*

The solution generation assistant focus area, on the other hand, generates solutions and suggests them to the AOM based on the case information and further criteria specified by the AOM at the time of solution generation. This focus area elicits information from the AOM about how to generate the solution, i.e. what criteria are most important. Depending on CCM, this might be done one of two ways. The first asks the AOM to specify objective function and provides weights or ranks to populate the objective function. The second asks the AOM to specify minimum or maximum bounds on criteria of interest. The first method of objective function specification is more appropriate for the Strategic CCM as this process seeks the “best” solution and subsequently lead to more iteration with the CWSS. The second method of boundary specification is more appropriate for the Tactical CCM as it may lead to less optimal solutions, but may require fewer iterations and thus require less time and effort.

### *Solution Evaluation Viewer*

The solution evaluation viewer focus area evaluates selected solution. Again, the information displayed should be tailored to each CCM. In the opportunistic mode, the evaluation need only be rudimentary so a limited number of criteria should be displayed and solution comparison does not need to be facilitated. However, in the tactical and strategic modes, comparison will need to be supported. Additionally in the strategic mode a greater number of attributes will need to be available than in the tactical mode.

### *Solution Evaluation Criteria*

The solution evaluation criteria focus area allows the user to specify acceptable, borderline and unacceptable levels of each criterion. As the criteria change with CCMs, here too the information will change with CCM design mode. For example, if only three criterion are used in the evaluation of a solution in the opportunistic design mode, then it would only be necessary to specify the acceptability levels for these three criterion, and not additional criterion used in the strategic design mode.

### *Execution Verification*

The execution verification focus area simply asks the AOM to verify that they do indeed wish to execute the solution that they have selected as a forcing function preventing a predictable error.

### *Coordination*

The coordination focus area allows the user to coordinate with colleagues via text messages as well as sending whole cases out for comment. In the opportunistic design mode, the AOM does not have time too coordinate heavily with his or her colleagues and the coordination focus are will therefore facilitate only advisory messages, i.e. advising colleagues of action taken, but not asking for advice or approval. In the tactical and strategic design modes, the focus area should also facilitate querying colleagues and soliciting their option about cases and solutions.



## 6.2 *Prototype Design*

With the UEDs complete, the user interfaces for each focus area and thus for the CWSS prototype as a whole were created. From the UEDs it was clear that the main CWSS prototype would provide the following focus areas on the screen by default:

- Case Organizer
- Case Viewer
- Solution Organizer
- Solution Viewer
- Solution Evaluation Viewer
- Coordination
- Schedule Organizer
- GDP Viewer
- Spare Aircraft Organizer

while the others would appear as needed as separate windows opened briefly when needed.

Before designing the user interface, consideration was given to the purpose of the prototype, i.e. testing the hypotheses stated in the first chapter using the methods outlined in Chapter 1 with only one AOM using the system at a time. Consequently, the Coordination feature of the CWSS was not necessary. The design and integration of that focus area is left for future development efforts.

By evaluating the UEDs and the Storyboards, a general layout was created with three main areas, as shown in Figure 58. In the top two-thirds of the window the viewers are organized as separate tabbed panels; only one of which is visible at a time. The bottom 1/3 contains both a small CCM Design Mode panel and a larger organizer panel. The design mode panel can be hidden during situations when the user is not given the option to select the design mode. The organizer panel is organized as separate tabbed panels similar to the viewer panel above. Between the viewer and organizer panels there are sixteen possible combinations of panels which may be shown (ignoring the CCM design mode panel). Table 8 shows all sixteen combinations and the most likely purpose for each.



**Figure 58:** General CWSS Layout

**Table 8:** CWSS Configuration Combination Likely Uses

Organizers	Viewers			
	Case	Solution	Evaluation	GDP
Case	Viewing cases	n/a	n/a	Looking at overall GDP impact
Solution	Solutions per case	Viewing solutions	Evaluating or comparing solutions	Double checking solutions
Spare Aircraft	Find spare AC for case	Modifying solution	n/a	n/a
Schedule	Determining supplementary schedule information	Determining alternative solution elements	n/a	n/a

**Problem Pad**

**Choose Problem Type:**

☐ Flight   
☒ Aircraft 186   
☐ Station

☐ Cabin Crew   
☐ Flight Crew   
☐ Other

**Duration** 60

**Problem Description/Notes**  
APU Light

**Cause** **Unscheduled Maintenance**

☐ Confirmed ☒ Suspected

**Blockage**

100  
75  
50  
25  
0

Cancel Submit

**Figure 59:** CWSS Case Entry Pad

### 6.2.1 Focus Area User Interface

With the overall layout of the prototype defined, the user interface details of each focus area was designed. Information from the UEDs regarding the links, double links, functions and purpose was used to inform the design.

#### *Case Entry Pad*

In many situations the AOMs will need a quick way to enter new cases, which is the purpose of Problem Pad. The AOM selects the type of problem and its source. In the case shown in Figure 59 the problem is with aircraft 186. The expected duration is 60 minutes. If the AOM has time and the information is available, he may enter in a more extensive problem description, choose a cause, and state whether the cause is suspected or confirmed at this point. The AOM will then submit the case.

In a fully functioning system, all six of the problem types could be available if the AOM

is responsible for all of them. For the prototype system, only the Flight, Aircraft and Station problem types were enabled because the evaluation tasks did not involve scheduling crew.

### *Case Organizer*

The case organizer has two different versions: one for the Opportunistic and the other for the Strategic and Tactical design modes. The two different versions are shown in Figure 60.

In the Strategic and Tactical modes the following information is available:

**Ref** The case's reference number

**Type** The case type: Station, Aircraft, Flight, Cabin Crew, Flight Crew

**Time In** The time the case was entered into the system

**Description** A short description of the problem, created by the user

**Type Specifics** A short description of the problem generated by the CWSS

**Active** A binary flag indicating whether an case is active or not

**TTR** Time remaining to resolve the problem

**Priority** The priority assigned to the case by the user

**Authority** Name of the AOM working the problem

**Resolved** A binary flag indicating whether the case has been resolved

**Cause** The cause of the problem as indicated by the user

The entries for the cases in the opportunistic mode include a subset of this information. For example, the status (active or inactive) column is not included in the Opportunistic mode because all cases in the Opportunistic mode are considered active. Additionally, the authority and priority columns are also not shown, as only cases belonging to the user are shown. The AOM is not expected to prioritize their cases beyond selecting the most important or immediate.

In the tactical and strategic modes, the Case Organizer allows the user to activate and deactivate cases using pop-up menus accessed via the right mouse button. In this way the AOMs can effectively sort the cases which are of interest to them at that moment. Additionally, as some problems may need repeated attention as better information is gathered or becomes more certain, the Case Organizer also allows the user to re-activate a case.



### *Case Viewer*

There are three different styles of case viewer: Opportunistic, Tactical/Strategic and GDP. The Opportunistic and the Tactical/Strategic Case Viewers are shown in Figure 61. Information assembled in the Opportunistic Case Viewer includes:

- Case type
- Case duration, start and end times
- Affected aircraft
- Passenger count for affected aircraft
- Case cause
- Case description (user entered)
- Case Log/Notes (automatically generated)
- Cause confirmation
- Impact of default solution

In the Opportunistic mode, the CWSS provides a preview of the impact of the problem that would result in simply delaying all of the affected aircraft by the minimum amount of time required. This is the default or minimum intervention solution. This solution is automatically calculated by the CWSS upon problem entry.

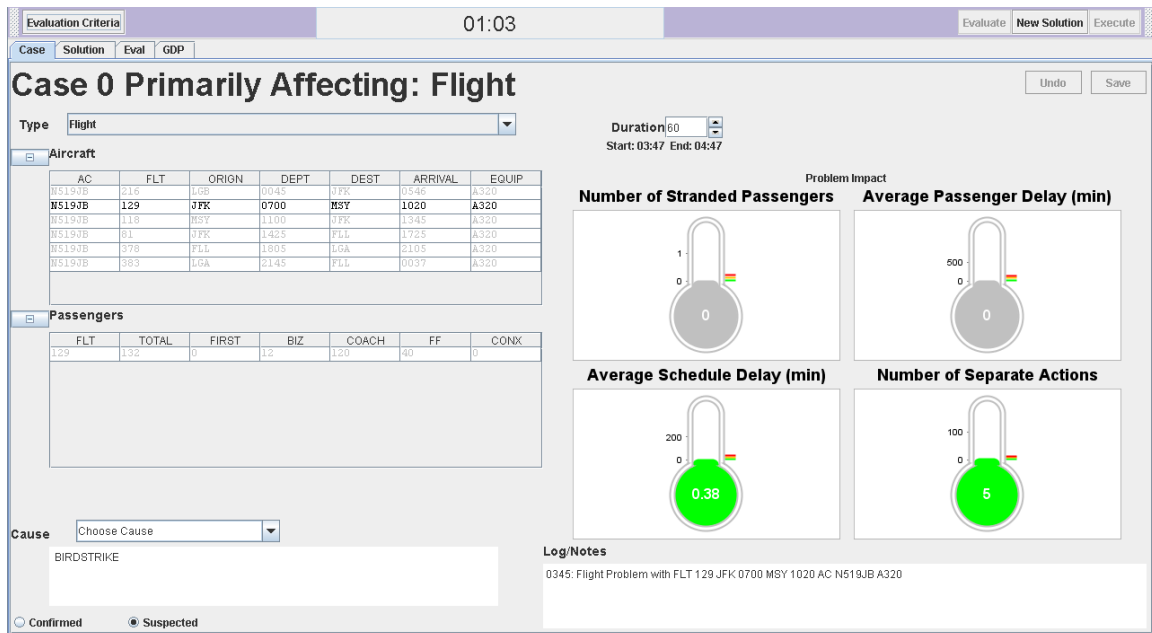
In the Tactical and Strategic modes, a priority slider is added so that the AOM may assign different cases different priorities, and a responsibility drop-down box is added so that the AOM may take in a case which will ultimately be the responsibility of another AOM.

The GDP style is shown in Figure 62, and is used regardless of Design Mode when the problem is a GDP. Thus, it uses a different layout which allows more room for longer lists of affected aircraft.

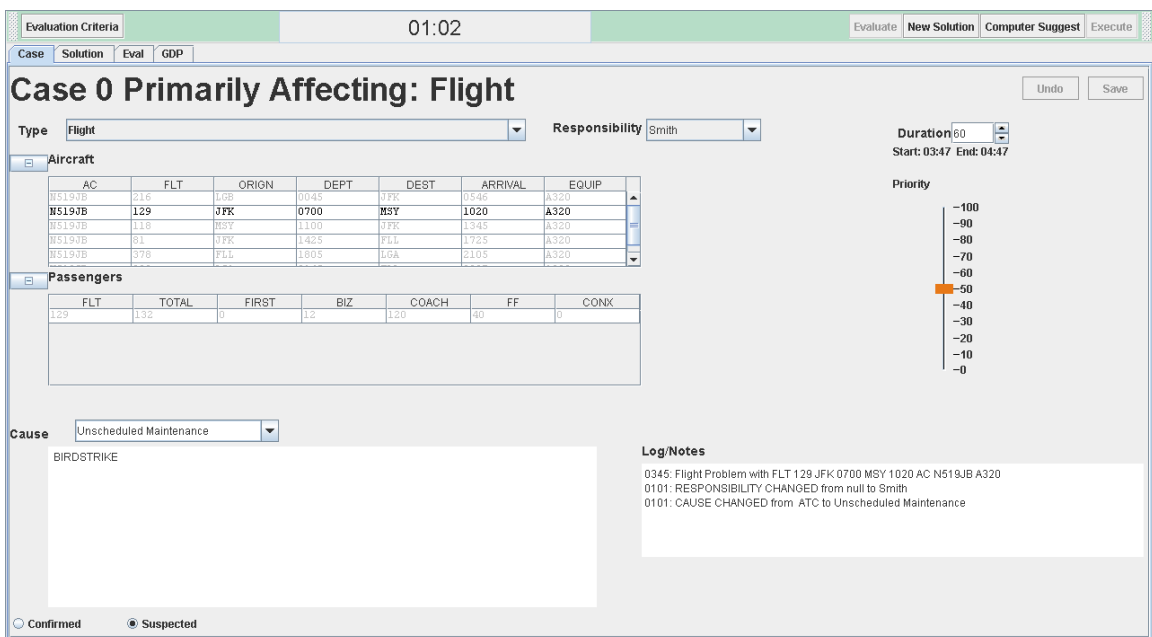
### *Solution Organizer*

The Solution Organizer consists of a table where the rows correspond to distinct solutions to a case and the columns describe each solution. The CWSS has only one version of the Solution Organizer containing the following information in columns:

**Solnum** Solution Reference Number

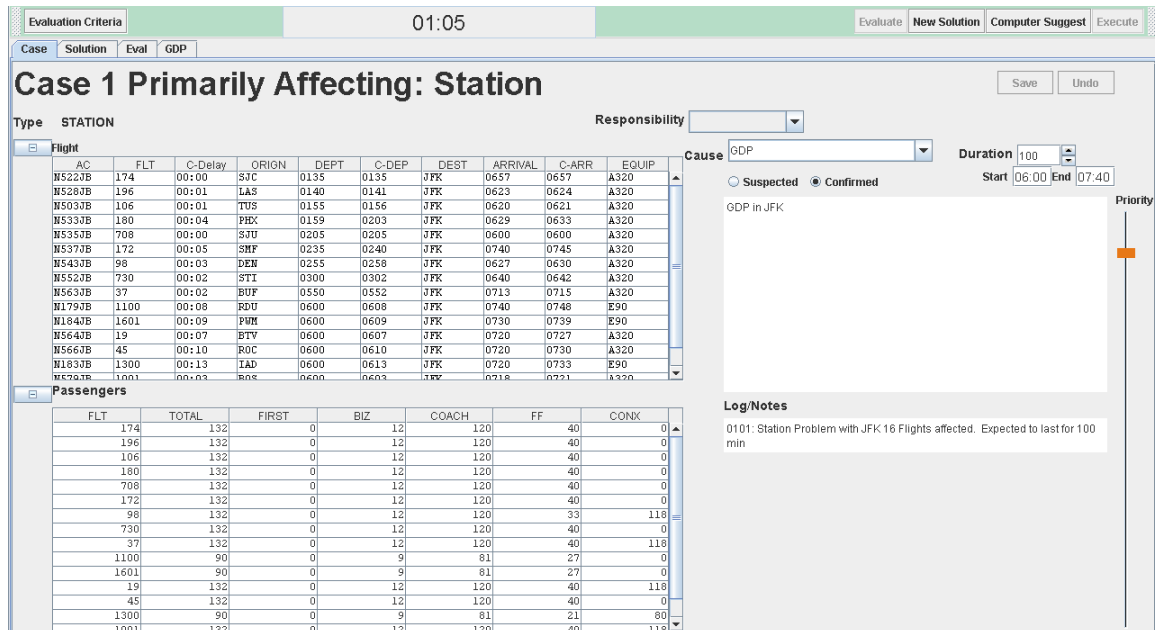


(a) Opportunistic



(b) Tactical or Strategic

**Figure 61: Case Viewer Focus Area**



(a) GDP

**Figure 62: CWSS GDP Case Viewer**

**Name** Solution name. In the prototype, the CS prefix means that it was generated by the CWSS, the next token is the name of the solution generation settings used; if no named settings have been used then it will display "LAST". The rest of the solution name consists of a summary of the different solution parts: delays, cancelations, swaps, new flights and GDP swaps.

**Delay** The number of flights delayed in this solution and their flight numbers

**Cancel** The number of cancelations in the solution and the corresponding flight numbers

**Swap** The number of equipment swaps in the solution and the swap description

**New** The number of new flights in the solution

**GDPSwap** The number of GDP slot swaps, and the swap description

In the Opportunistic Mode, only one solution is kept at a time, so there is only ever one solution in the Solution organizer. Additionally, a default solution will be automatically calculated by the CWSS upon case entry and labeled "Default".

### *Solution Viewer*

The Solution Viewer details the solution in a series of tables which describe the Delays, Cancelations, Equipment Swaps, New Fights and GDP Swaps. Each table can be minimized to provide a better view of the different elements in each solution.





Evaluation Criteria

01:06

EvaluateNew SolutionExecute

CaseSolutionEvalGDP

Solution: Default

ModifySaveUndo

Delays (5)

AC	FLIGHT	DELAY	ORIGN	ORIG DEPT	NEW DEPT	DEST	ORIG ARR	NEW ARR
N519JB	129	60	JFK	0700	0800	MSY	1020	1120
N519JB	118	50	MSY	1100	1150	JFK	1345	1435
N519JB	81	40	JFK	1425	1505	FLL	1725	1805
N519JB	378	30	FLL	1805	1835	LGA	2105	2135
N519JB	383	20	LGA	2145	2205	FLL	0037	0057

Cancellations (0)

Equipment Swaps (0)

New Fights (0)

scheduled on an aircraft or suggesting additional cancelations to balance the aircraft load at the different airports.

### *Solution Generation Assistant*

The Solution Generation Assistant aids the AOM in creating viable solutions. There are two types of Solution Generation Assistants, one for the Tactical mode and one for the Strategic mode, shown in Figure 66. In the Tactical mode, which is characterized by satisficing, the Solution Generation Assistant allows the AOM to specify the constraints for acceptable solutions. In this example the AOM has asked the CWSS to suggest solutions which limit the average passenger delay to less than 114 minutes, limit the % missed connections to less than 30 and the load factor at to least 80%. If no solutions can meet these criteria the AOM is notified here.

In the Strategic mode, which is characterized by an attempt to globally optimize, the AOM is allowed to specify the optimization criteria, either via direct weightings or rankings. In this case the AOM has chosen to only weight three criteria, minimizing passenger delay, minimizing the number of spare aircraft used and maximizing the load factor. The top five solutions will be returned which maximize the utility as specified by these linear weightings.

In both modes, the criteria set can be saved for future use. If saved, the name given to the criteria set will be displayed in the Solution Organizer under the Solution Name column.

### *Solution Evaluation Viewer*

The Solution Evaluation Viewer allows the AOMs to evaluate the individual solutions along a number of different dimensions. The different styles of evaluation is shown in Figure 67. As only one solution will be considered at a time, the Opportunistic mode Evaluation Viewer consists of four thermometer plots which indicate 1) the number of stranded passengers 2) the average passenger delay 3) the average schedule delay and 4) the number of separate actions required by this solution as a measure of solution complexity. The four criteria levels of acceptability translated here in to green/yellow/red colors is set in a separate focus area called the Solution Evaluation Criteria Chooser which can be accessed at any time from the upper left hand corner button labeled Evaluation Criteria and as discussed next. The color

Solution Creation

Add Component

New Flight

Swap Flights

Move Flight(s)

Cancel Flight(s)

Delay Flight(s)

Swap Aircraft

Swap GDP Slots

Solution Summary

Clear All

Complete

GDP Complete

Save As

+

Cancellations

AC	FLIGHT	ORIGIN	DEPT	DEST	ARRIVAL

+

Delays

AC	FLIGHT	DELAY	ORIGIN	ORIG DE...	NEW DEPT	DEST	ORIG ARR	NEW ARR

+

Aircraft Swaps

FLT	NEW AC	ORIGIN	DEPT	DEST	ARRIVAL	ORIG AC

+

New Flights

AC	FLIGHT	ORIGIN	DEPT	DEST	ARRIVAL

+

GDP Slot Swaps

AC	FLIGHT	ORIGIN	SCHED ARR	ORIG C-ARR	PRE SWAP...	POST SWA...	FINAL C-A...

**Figure 65:** CWSS Solution Completion Assistant

**Solution Suggestion Criteria**

Favorites

**Default Suggestion Criteria**

Minimum Acceptable      Maximum Acceptable

114

30

0      80

Select criteria for the computer

- ☒ Minimize average PAX delay
- ☐ Minimize average business class PAX delay
- ☐ Minimize average frequent flyer PAX delay
- ☒ Minimize % missed connections
- ☐ Minimize % business class missed connections
- ☐ Minimize % frequent flyer missed connections
- ☐ Minimize number of spare aircraft used
- ☐ Minimize average schedule delay
- ☐ Minimize % of flights canceled
- ☒ Maximize load factor

Save As    Cancel    Suggest

(a) Tactical

**Solution Suggestion Criteria**

Favorites

**DEFAULT Criteria**

Weight      Rank

100

Save As    Cancel    Suggest

(b) Strategic

**Figure 66:** CWSS Solution Generation Assistant

coding should allow the AOMs to quickly assess a solution's acceptability.

In the Tactical and Strategic modes direct solution comparison is facilitated. Correspondingly, the thermometer plots have been replaced with box and bar charts. In the Tactical mode, in addition the the four evaluation dimension considered in the Opportunistic mode, airline load factor is included and passenger data is broken down into the different types of passengers. The levels of acceptability are portrayed as green/yellow/red lines drawn across the charts, and are set in a similar fashion to those in the Opportunistic mode.

In the Strategic mode, the number of dimensions again increases for a total of six parameters visible at a glance. In this mode there is a much higher degree of specialization allowed in that the AOM can choose to place any chart in any location and can choose to view any 6 of 9 criteria. Additional options include both the number and percentage of stranded passengers and missed connections.

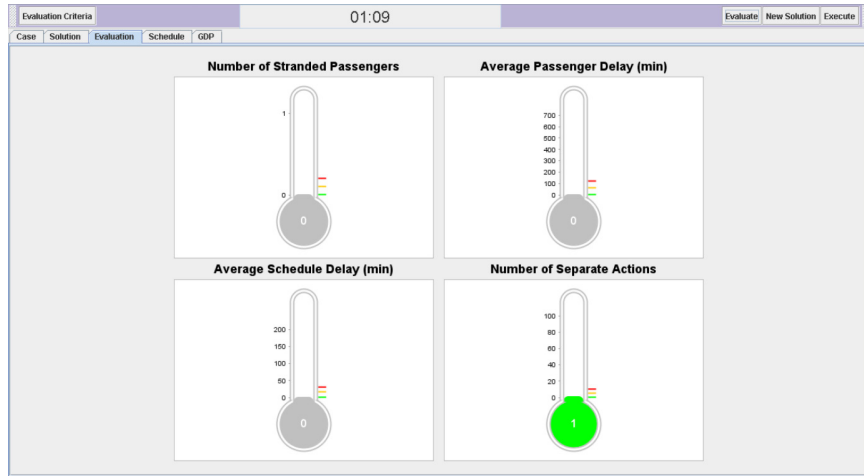
Comparing multiple solutions is accomplished by selecting multiple solutions using the Solution Organizer. Using the shift and control keys on the keyboard any combination of solutions can be evaluated simultaneously, although this layout is best suited to four or five solutions at a time. Figure 68 shows the Tactical and Strategic Solution Comparison.<sup>1</sup>

#### *Solution Evaluation Criteria Chooser*

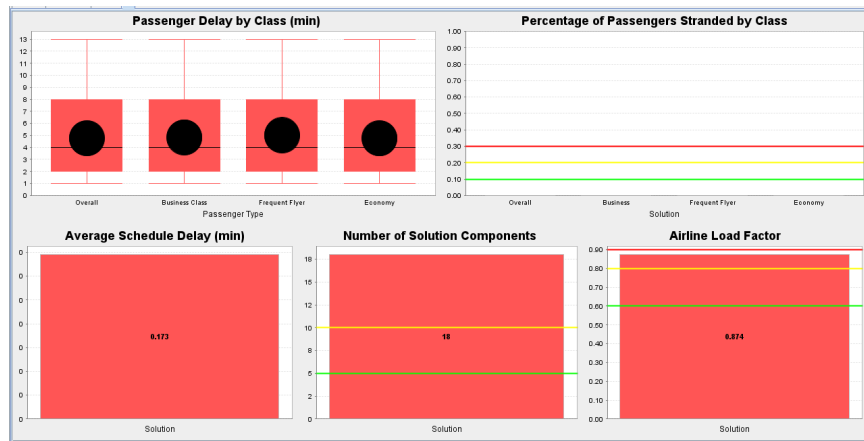
The Solution Evaluation Criteria Chooser allows the AOM to specify the acceptable level of each evaluation criteria. It can be accessed at any time from the upper left hand corner button labeled Evaluation Criteria, and has two version; Opportunistic and Tactical/Strategic. as shown in Figure 69. In the Opportunistic mode the number of evaluation criteria is set to the four criteria displayed in the Evaluation Viewer. In the Tactical and Strategic mode the number of evaluation criteria is not set, and all nine possibilities are available. Different sets of criteria can be preset using the 'save as' function and then activated when appropriate.

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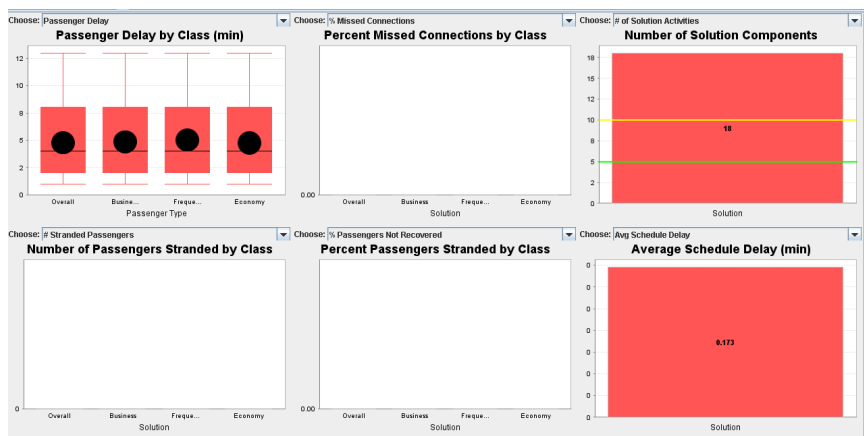
<sup>1</sup>While it is not in the best interest of the CWSS to use red as one of its primary colors for the evaluation figures, the Java graphics software underlying the prototype did not allow an alternate color scheme.



(a) Opportunistic

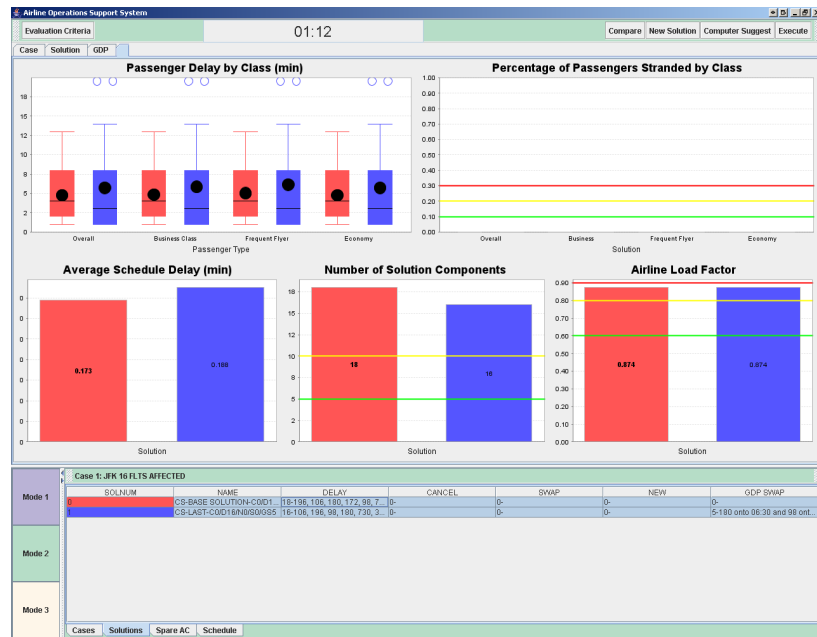


(b) Tactical

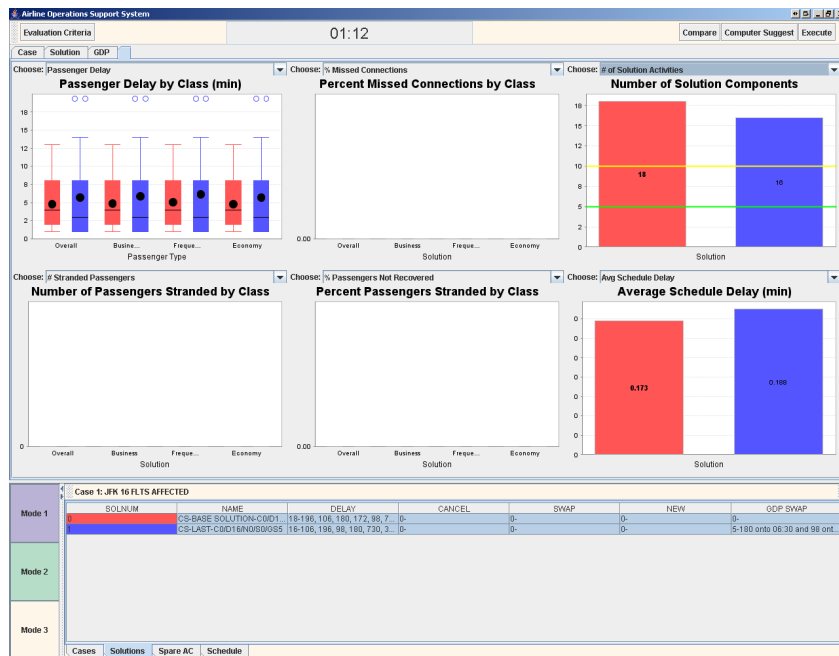


(c) Strategic

Figure 67: CWSS Solution Evaluation Viewer



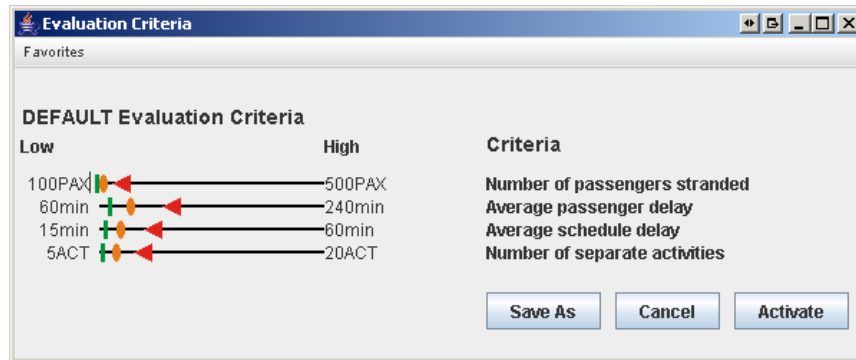
(a) Tactical



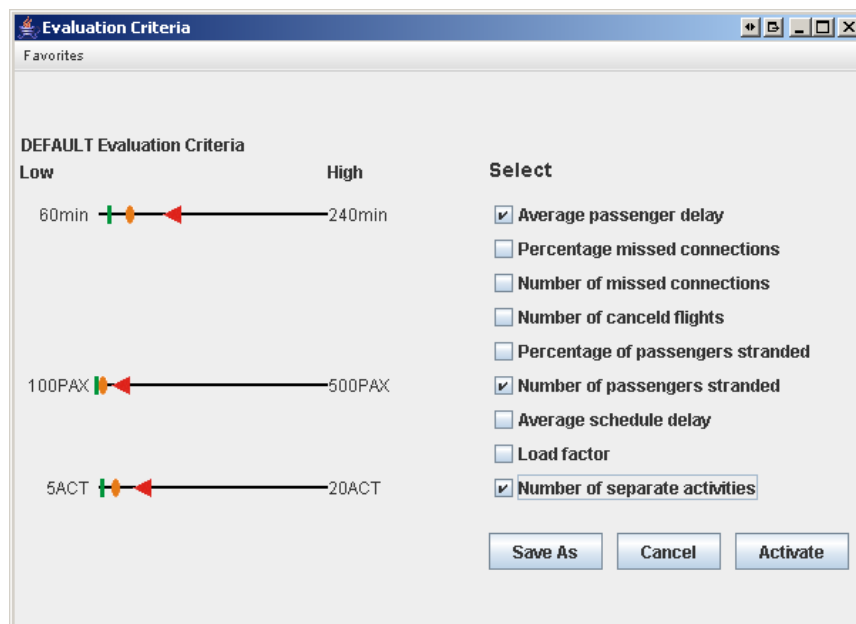
(b) Strategic

Figure 68: CWSS Solution Comparison



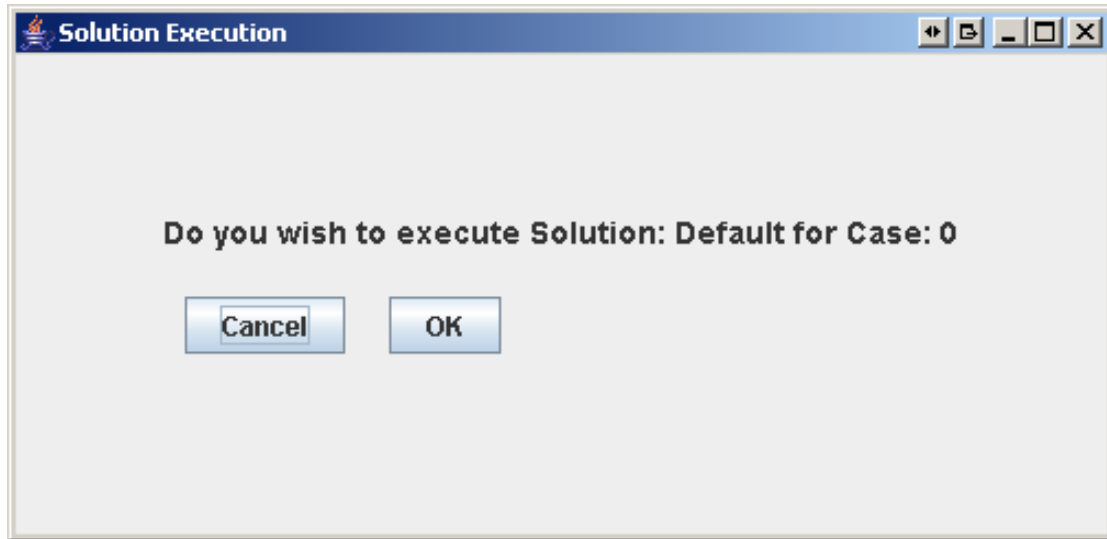


(a) Opportunistic



(b) Tactical or Strategic

**Figure 69:** CWSS Evaluation Criteria Chooser



**Figure 70:** CWSS Solution Execution Verification

### *Execution Verification*

The Solution Execution Verification focus area, shown in Figure 70 simply provides the AOM a chance to confirm that the currently selected solution is the solution that they wish to execute.

### *Schedule*

The Schedule Organizer allows the AOMs to view the schedule in a tabular format and to sort and filter the schedule. Each of the rows in the table correspond to a specific flight and the columns correspond to:

**FLT** Flight number.

**ST** Current status of the flight.

**DELAY** Amount of delay currently posted in the system

**ORIGIN** Flight origin.

**DEP** Flight departure time as currently listed. Times in parentheses are original schedule departure times, only shown when the flight is delayed.

**DEST** Flight destination.

**ARR** Flight arrival time as currently listed. Times in parentheses are original schedule arrival times, only shown when the flight is delayed.

Flight No.												Dep Station	Arr Station	Equip	Tail No.	Delay > 0					
0	2	4	6	8	10	12															
FLT		ST		DELAY		ORIGIN		DEP		DEST		ARR		PAX		EQP		TAIL		TOGA	
358	air			0000		BUR		0000		JFK		0504		132 (118)		A320		N504JB		0111	
186	air			0000		SAN		0005		JFK		0510		132 (0)		A320		N505JB		0105	
90	air			0000		OAK		0015		JFK		0525		132 (0)		A320		N506JB		0120	
243	air			0000		LGB		0020		FLL		0458		132 (0)		A320		N509JB		0102	
488	air			0000		LGB		0020		BOS		0532		132 (0)		A320		N510JB		0108	
300	air			0000		LGB		0030		IAD		0502		132 (0)		A320		N516JB		0138	
420	air			0000		PHX		0040		BOS		0535		132 (0)		A320		N517JB		0145	
216	air			0000		LGB		0045		JFK		0546		132 (0)		A320		N519JB		0114	
92	ground			0000		SLC		0125		JFK		0535		132 (0)		A320		N520JB		1710	
Cases		Solutions		Spare AC		Schedule															

**Figure 71: CWSS Schedule**

**PAX** Total number of passengers on the flight. Number in parentheses is the number of connecting passengers. Mouse-overs provide detailed information on connecting passengers.

**EQP** Aircraft equipment type on flight.

**TAIL** Specific tail number for aircraft on flight.

**TOGA** Time on ground after arrival at destination.

Important stations are color coded to allow the AOMs to more quickly find their associated flights. There are multiple ways to manipulate the schedule data. First the data may be sorted by clicking on any of the column headers. Second, the data may be filtered by either positioning the slider to show the time window of interest or entering the parameters of interest into the text boxes along the top row.

### *GDP Viewer*

The GDP Viewer works in much the same way as the Schedule Organizer. It provides information on only a specific GDP, but provides more information about the flights based on the arrival slot assigned to each flight and the corresponding controlled release time. The information can be sorted and filtered in much the same way as the schedule. For multiple GDPs multiple Tabs are created.

## **6.3 Summary**

This chapter has described the creation of a UED and a software prototype. UED creation focused on designing information flow and functionality. Then, the Protopye design filled in the details on user interface and information presentation form. Screen shots of the entire prototype are shown in Figures 68 and 73-77.



Airline Operations Support System

01:03

EvaluateNew SolutionComputer SuggestExecute

CaseSolutionEvalGDP

Case 0 Primarily Affecting: Flight

TypeFlightResponsibility

Duration60

Start: 03:47 End: 04:47

Priority

-100

-90

-80

-70

-60

-50

-40

-30

-20

-10

-0

Aircraft

AC	FLT	ORIGIN	DEPT	DEST	ARRIVAL	EQUIP
N519JB	216	LGA	0045	JFK	0346	A320
N519JB	129	JFK	0700	MSY	1020	A320
N519JB	118	JFK	1100	JFK	1345	A320
N519JB	81	JFK	1425	FLI	1725	A320
N519JB	378	FLI	1805	LGA	2105	A320
N519JB	383	LGA	2145	FLI	0037	A320

Passengers

FLT	TOTAL	FIRST	BIZ	COACH	FF	CONK
129	132	0	12	120	40	0

CauseChoose Cause

BIRDSTRIKE

Log/Notes

0345: Flight Problem with FLT 129 JFK 0700 MSY 1020 AC N519JB A320

ConfirmedSuspected

Case 0: FLT 129 JFK 0700 MSY 1020 AC N519JB A320

Add Case

Mode 1

Ref	Type	Time In	Description	Type Specifics	Active	TTR	Priority	Authority	Resolved	Cause
0	Flight	03:45	BIRDSTRIKE	FLT 129 JFK 0700 MSY 1020 AC N519JB A320	true	05:57	50		false	ATC
1	Station	01:01		JFK 16 FLTS AFFECTED	true	00:31	90		false	GDP

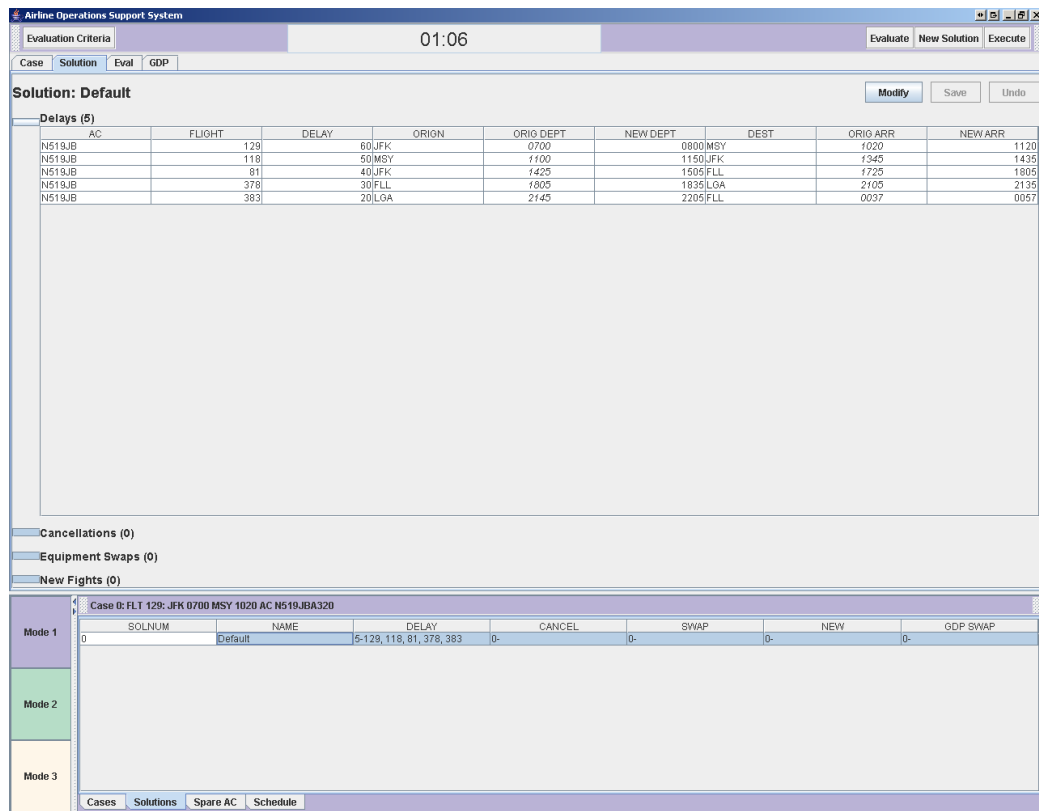
Mode 2

Mode 3

CasesSolutionsSpare ACSchedule

**Figure 74:** CWSS Prototype Screen Shot of Case Viewer and Case Organizer in the Tactical Design Mode

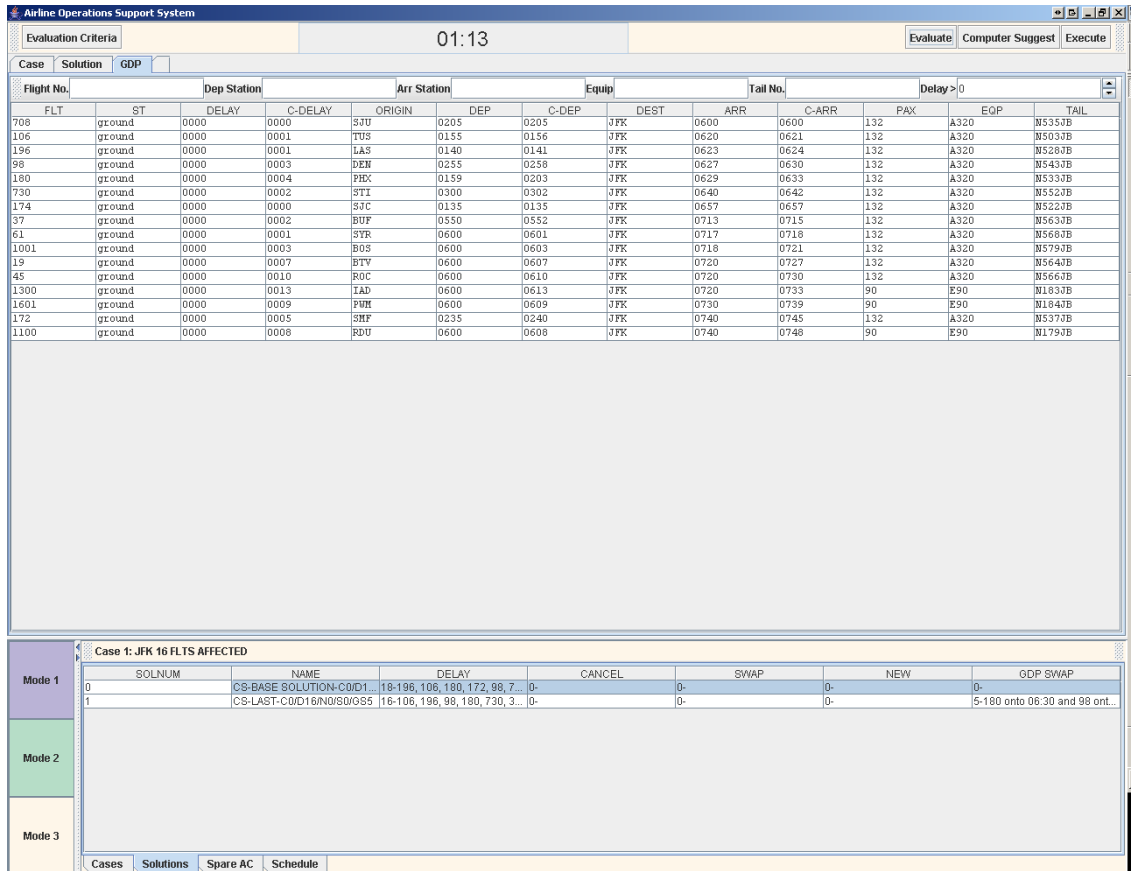
163



**Figure 75:** CWSS Prototype Screen Shot of the Solution Viewer and Solution Organizer in the Opportunistic Design Mode



**Figure 76:** CWSS Prototype Screen Shot of the Evaluation Viewer and Solution Organizer in the Opportunistic Design Mode



**Figure 77:** CWSS Prototype Screen Shot of the GDP Viewer and Solution Organizer in the Strategic Design Mode



In this chapter we have shown how it to incorporate multiple contextual control modes into the contextual design process. Specifically we have created a cognitive work support system with three distinct operating modes corresponding to the Opportunistic, Tactical and Strategic Contextual Control Modes. As described in the following chapter, the prototype will be used to test the hypotheses that individuals using a support system which matches their operating CCM will lead to increased task performance.

## CHAPTER VII

### CWSS ASSESSMENT

#### **7.1 *Experiment Description***

A controlled experiment examined the effectiveness of improving performance by designing the CWSS to match individuals' immediate CCMs. Individuals were tasked with using the CWSS set to a specific design mode (DM), to minimize the impact on their airline (in terms of passenger disruption and aircraft utilization) in scenarios intended to demand different CCMs. The controlled experiment tested for differences in performance, workload and patterns of activity.

##### **7.1.1 Participants**

Nine people participated. The three 'expert' participants were AOM's working for a single major airline with an average experience of 22 years working in airline operations and 3.8 years working as an AOM. Several had experience working for other airlines prior to their current employer, and one was a previous member of a task force to develop a decision support system for airline operations. Three more participants had a working knowledge of airline operations, but no operational experience. Two of these individuals had experience working for a major airline and including working in the aviation safety group and engineering line support. These individuals were considered 'knowledgeable'. The remaining three participants were graduate students at Georgia Tech who had no experience with airline operations. These participants were considered 'novices'.

##### **7.1.2 Experimental Task and Procedure**

Using the CWSS, participants were instructed to maintain an airline schedule to the best of their abilities during each scenario despite between one and three problems that would send the airline into irregular operations without intervention. The first disruption was observable at the beginning of the scenario and the other two, where included, became

observable later. The participant’s overall goal was to resolve all of the disruptions within a given time limit.

The three scenario types corresponded to the different CCMs. Opportunistic scenarios had three problems which involved either a single flight or aircraft. Tactical scenarios had two problems: one which involved a single flight or aircraft and one which was a small ground delay program (GDP) affecting 3-6 flights. Strategic scenarios had a single GDP problem which involved 6-10 flights. For the novices and the knowledgeable participants a fixed time limit of 10 minutes was employed for all of the scenario types. For the experts time limits of 5, 8 and 12 minutes were used with the opportunistic, tactical and strategic scenario types, respectively. The inclusion of the varied time limits was necessary for experts, as the performance of a preliminary participant had demonstrated that, without them, the scenarios did not induce scrambled or opportunistic CCMs.

### **7.1.3 Experimental Design**

The experimental design of was a cross-over design with each subject evaluating all three CWSS DM. Time limit was held constant (except for the expert participants) and the scenario types and run order balanced within CWSS Design Mode blocks. Table 9 illustrates the crossover design of experiments. Scenarios A-C are opportunistic. Scenarios D-F are tactical. Scenarios G-I are strategic. The scenario briefings used in the experiment are located in Appendix B on page 238. Note that the conditions where performance is hypothesized to increase due to a match between the participant’s CCM and the CWSS DM are marked with an asterisk.

To further reduce the bias possibly conferred by referring to the different CWSS DM’s by name, the CWSS DM’s were instead distinguished by a code word. The code words were colors which corresponded to the border color used in each of the CWSS DMs. The CWSS’ strategic DM was given an orange border and was referred to by the participants and the questionnaires as the “orange form”; the CWSS’ tactical DM was given a green border and was referred to as the “green form”; the CWSS’ opportunistic DM was given a purple border and referred to as the “purple form”.

**Table 9:** Experimental Design

	Opportunistic DM			Tactical DM			Strategic DM			
Subject	Run 1	Run 2	Run 3	Run 4	Run 5	Run6	Run 7	Run 8	Run 9	Run 10
1	A*	D	G	B	E*	H	C	F	I*	J
2	H	B*	E	I	C	F*	G*	A	D	J
3	F	I	C*	D*	G	A	E	H*	B	J
	Tactical DM			Strategic DM			Opportunistic DM			
Subject	Run 1	Run 2	Run 3	Run 4	Run 5	Run6	Run 7	Run 8	Run 9	Run 10
4	G	A	D*	E	H*	B	F	I	C*	J
5	E*	H	B	C	F	I*	A*	D	G	J
6	C	F*	I	G*	A	D	H	B*	E	J
	Strategic DM			Opportunistic DM			Tactical DM			
Subject	Run 1	Run 2	Run 3	Run 4	Run 5	Run6	Run 7	Run 8	Run 9	Run 10
7	D	G*	A	H	B*	E	I	C	F*	J
8	B	E	H*	F	I	C*	D*	G	A	J
9	I*	C	F	A*	D	G	B	E*	H	J

\*indicates matching mode

#### 7.1.4 Dependent Measures

The dependent variables of interest include performance, time spent on each CWSS window, transitions between CWSS windows, participant assessment of the CWSS, and self-assessed CCM.

**Performance** Performance was assessed by assigning a cost to each action taken by the participant (e.g. delaying a flight) and summing costs across all the actions. The process for calculating performance is described in p. 171. Participants were not made explicitly aware of the numerical costs for each type of delay, but were told that passenger delay and schedule delay would be used to derive performance. Additionally, the costs were reflected in the solution evaluation and solution generation presented by the CWSS.

**Time per CWSS element** The amount of time spent on each CWSS element was measured so that any pattern of behavior can be detected, whether associated with time limits, CCM, scenario or CWSS DM.

**Transition between CWSS elements** Similar to the amount of time spent on each

CWSS element (or window), the choice of next element was recorded.

**Self-assessed CCM** Each participant was asked at the end of each run to indicate their CCM on a 10 point scale based on de-identified CCM definitions; strategic mode was labeled S-mode, tactical was labeled T-mode, opportunistic mode was labeled O-mode and scattered mode was labeled SC-mode. Additionally, as previous studies have shown that self-assessments of CCM correlate highly with perceived performance, this study had participants assess their CCM via a survey instrument populated with indirect questions [29]. The experimental test booklet, included in Appendix A includes copies of these indirect questions.

**CWSS Assessment** At the end of the experiment, the participants completed a short questionnaire to find if the participants felt the CWSS was helpful to them, and why.

**Workload** At the end of each scenario, the participants were asked to assess their workload using the six NASA TLX sub-scales.

**Choice of CWSS Mode** In the final run, each participant had opportunity to choose which the CWSS DM they wanted to use. This choice was compared to the self-assessed CCM and to their performance with the same CWSS mode for previous runs.

#### *Performance Calculation*

Four factors were used to calculate the overall cost of a specific solution: the value of an economy class passenger's time per minute, value of a business class passenger's time per minute, the value of aircraft operating cost per minute and the value of 1% increase in the airline load factor. Values and costs were all in 1994 dollars and were taken from the Federal Aviation Administration's report on the total cost for airline carrier delay [19].

**Economy Passenger Time Value** \$42.92 per hour

**Business Passenger Time Value** \$64.40 per hour

**Aircraft Operating Cost** \$1495 per hour

**Airline Load Factor Value** \$80 per percent Load Factor

Each schedule disruption had a default solution which involved delaying flights until the originally scheduled equipment was available. Problems which were not solved before the end of time were assigned a cost of the 110% of default solution. Incomplete or erroneous solutions were assigned a cost of 115% of the default solution. These cases were rare; only 3 runs had solutions which were incomplete or erroneous.

These costs were used to calculate each solution's cost. As the cost of each disruption's solution set had a different range (some disruptions were inherently more costly than others) the solution's default cost was taken as a baseline and set to zero. Each run's cost was normalized using the default solution cost such that the greater the derived performance value the lower the solution cost with respect to the default cost. The performance for all scenarios then fell into a range of between -0.16 and 1.00.

$$Performance = \frac{(DefaultCost - ActualCost)}{DefaultCost} \quad (1)$$

#### 7.1.5 Experiment Protocol

The experimental protocol is outlined in the Experiment Test Booklet, found in Appendix A. At the start of the evaluation participants were read the introductory briefing and then asked to read and sign the informed consent form. Participants were then trained on the specific tasks they were expected to perform. This training included a description of the fictitious airline, their responsibilities and capabilities, the actions available to them, and, for novice and knowledgeable participants, typical strategies employed by AOMs to solve problems. Participants were trained on one form of the CWSS at a time. Following their training they were asked to complete three scenarios using the corresponding CWSS DM. The process was repeated for the following two CWSS DMs. For example, Participant 1 was first trained on the opportunistic DM form of the CWSS (followed by 3 data collection runs in opportunistic), then on the tactical (followed by 3 data collection runs in tactical) and finally on the strategic (followed by 3 data collection runs in strategic). In the final run, participants were instructed to use which ever CWSS DM they wished, and that they were free to switch DMs at any time. Following each scenario they were asked to complete

a questionnaire which included a NASA TLX, and two CCM questionnaires. At the end of experiment the participants were asked to fill in a questionnaire which examined their understanding of the CWSS DM's, the appropriateness of the different design modes for different circumstances and the CCM's usability.

#### **7.1.6 Data Analysis**

The data analysis sought to answer the following questions:

1. Was participant performance higher and the workload lower when the CWSS Design Mode matched the participant's CCM?
2. Was CWSS usage affected by scenario type, CWSS DM, or self-assessed CCM?
3. In the final run, did the participants choose the CWSS mode which was most appropriate for the situation, i.e., that matched their CCM and/or that maximized their performance?
4. How do we measure CCM?
5. Did the design process produce a CWSS whose modes meet user's needs?

As the type of data collected for each measure and the nature of each question is different, a variety of statistical techniques was used, including: General Linear Models (GLM), General Estimating Equations (GEE) which extends GLM to accommodate correlated repeated measures data; Linear Mixed Models (LMMs) which expand the GLM to model random effects and fixed effects separately and to accommodate data that exhibits correlated and non-constant variability; and Friedman two way ANOVA. All LMMs modeled subjects as random effects, CWSS DM and Scenario Type as within subject fixed effects, and expertise as a between-subject fixed effect. Significance was set at the 0.05 level and marginal significance at 0.10. When significant differences were found in factors with more than two levels, a pairwise comparison with a Bonferoni correction was conducted.

### **7.2 *Experiment Results***

#### **7.2.1 Performance**

Participant performance was derived using the method described in Section 7.1.4 and yields a continuous scale measure of performance where the greater the score the better the performance. A LMM was used to analyze the effect of scenario, scenario type, run order, CWSS DM, and expertise on performance. The results are summarized in the following sections.

**Table 10:** Performance Analysis Summary

Independent Variable	Significant Influence
Scenario	Yes
Run Order	No
Scenario Type	No
CWSS DM	Marginally
Expertise	No

### *Scenario & Run Order*

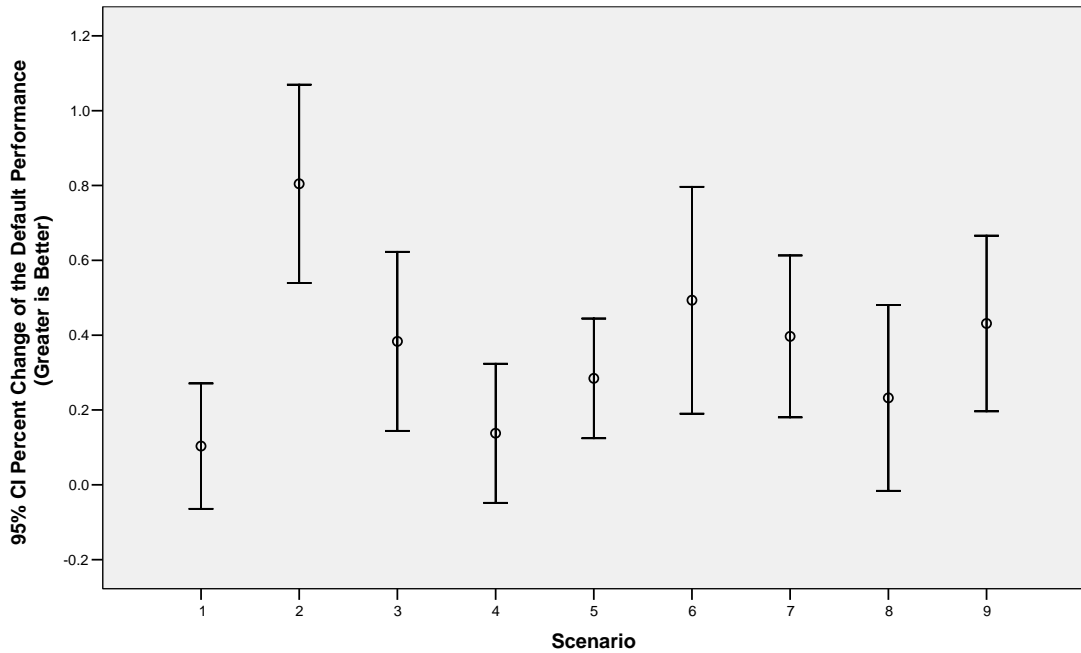
To verify that the scenarios were comparable, a LMM was performed in which the scenario was the only predictor included in the model for Scenarios 1-9. Scenario 2 was found to have significantly higher performance than all of the other scenarios  $F(1, 9) = 27.336$   $p \leq 0.000$ , as shown in Figure 78, and unlike the other opportunistic scenarios. Scenario 2 had only two discrete problems, one of which was given to the participants in two parts, as is often the case in airline operations. The first part of the problem was given to the participants with the caveat that maintenance had not yet determined how long the aircraft would be unavailable, but that it would last at least 45 minutes. Later in the scenario, the participants were informed that the aircraft would be unavailable for several hours. It was anticipated that the participants would attempt to solve the problem twice. However, it turned out that, in the more stressful situations, the participants simply ignored the problem while continuing to work on the first problem until the second half of the problem was called in. Consequently, Scenario 2 data was excluded in the subsequent performance analyses.

A LMM was performed which included only the run order for Scenarios 1-9. No significant difference was found between the first and the last run  $F(1, 8) = 1.813$   $p \leq 0.119$ .

### *Scenario Type, CWSS DM & Expertise*

To test the effect of the three independent variables of interest, a LMM was performed which included the scenario type, the CWSS DM, expertise and all two-way interactions for the first nine scenarios. No statistical significant differences were found between scenario type or expertise. There was a marginally significant effect for CWSS DM  $F(2, 23) = 3.099$   $p \leq 0.064$ , as shown in Figure 79. Pairwise comparison revealed that performance in



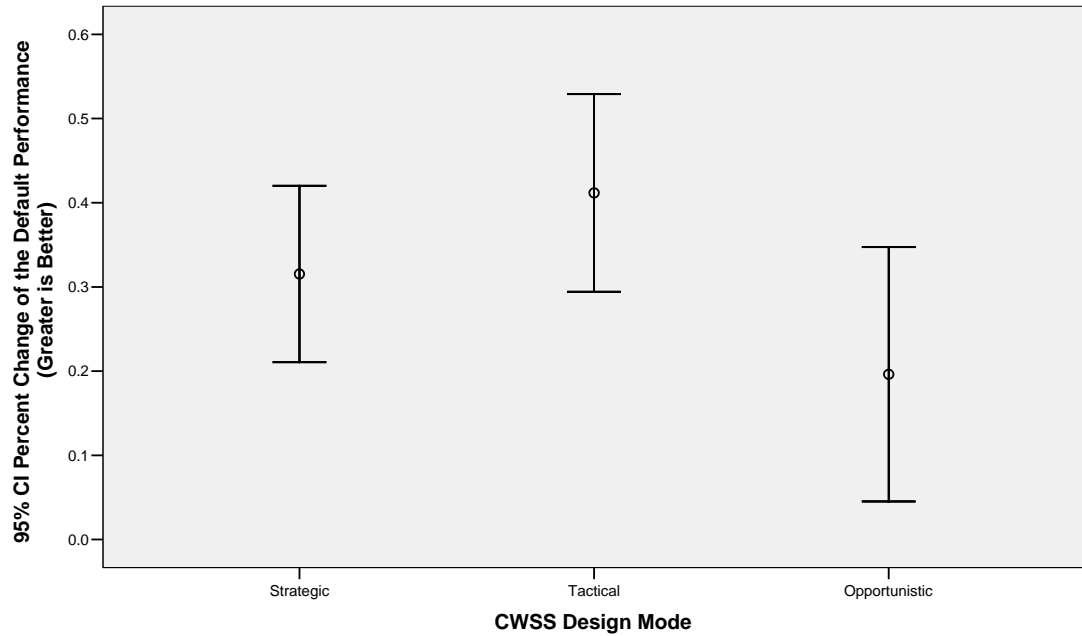


**Figure 78:** Performance by Scenario

the tactical CWSS DM was better than in the opportunistic CWSS DM, with marginal significance,  $p \leq 0.069$ . None of the factor-interactions were statistically significant.

#### *Matching CWSS DM Cases*

One of the key questions of this evaluation was if performance improves when an individual's CCM matches the CWSS DM. The evaluation tested this in two ways. First, it sought to push participants into a certain CCM through a combination of task loading, task type and, with the expert participants, time limits. Accordingly, a LMM analysis compared performance in cases where the Scenario Type matched the CWSS DM to cases where it did not. Second, the evaluation asked the participants to self-assess their CCM. A second LMM analysis was used to compare performance in cases where the self-assessed CCM matched the CWSS DM. No statistical difference was found between performance in scenario type and CWSS DM matching and non-matching cases. Similarly, no statistical difference was found between performance in cases where self-assessed CCM and CWSS DM matched versus cases where they did not.



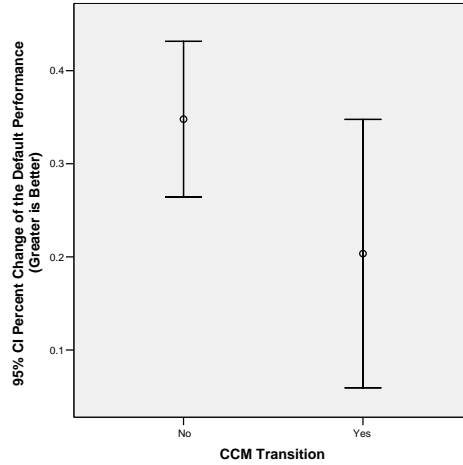
**Figure 79:** Performance by CWSS Design Mode

#### *CCM & CCM Transition*

The preliminary experiment described in Chapter 3 indicated that performance was independent of the self-assessed CCM. A LMM was used to analyze the effect of self-assessed CCM on performance, and, as expected, no significant effect was found. Transitions between CCM's were, however, linked to higher levels of frustration. A LMM analyzed the effect of CCM transition on performance, revealing a statistically significant  $F(1, 35) = 8.113$   $p \leq 0.007$  difference; participants who reported transitioning between CCMs performed worse than those who did not, as shown in Figure 80.

#### *Performance Analysis Summary*

Overall, performance was uniformly good, making it difficult to differentiate between different CWSS DM. This is a common problem in evaluating decision aids, which has led to much discussion about the need for additional metrics beyond performance to measure the effectiveness and usefulness of computer systems or user interfaces. Workload can provide additional insight beyond observable performance. Thus, the next section will analyze the impact the independent variables and the matching cases had on workload.



**Figure 80:** Performance by CCM Transition

**Table 11:** Significance Level Summary

		TLX Sub-scales				
		Mental	Temporal	Performance	Effort	Frustration
CWSS DM	$p \leq$	0.209	0.596	0.601	0.412	0.746
Scenario Type	$p \leq$	<b>0.001</b>	<b>0.005</b>	<b>0.018</b>	0.643	0.863
Expertise	$p \leq$	<b>0.001</b>	0.973	<b>0.002</b>	0.246	<b>0.001</b>

### 7.2.2 Workload

Workload was measured using the NASA TLX subjective rating sub-scales. Each sub-scale was considered to be a continuous measure of workload. A LMM was performed to determine the effect of scenario type, CWSS DM, and expertise on performance on all of the subscales except physical effort, as it was not of interest. The results are summarized in Table 11.

#### *CWSS DM & Scenario Type*

CWSS DM had no significant effect on any of the TLX sub-scales. Scenario type had a significant effect on the mental, temporal and performance sub-scales as shown in Figure 81. For the mental and temporal sub-scale the opportunistic scenarios were rated significantly harder than either the tactical or strategic. For the Performance sub-scale the opportunistic scenario type was rated significantly harder than the tactical scenario type. These results may have resulted from the larger number of distinct problems given in the opportunistic

scenarios.

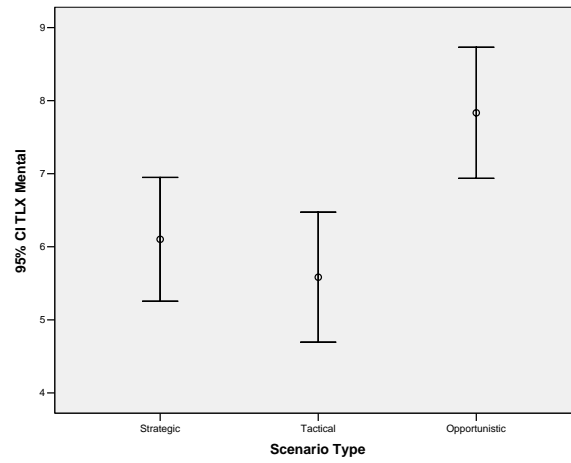
### *Expertise*

Expertise had a significant effect on the Mental, Performance and Frustration sub-scales, as shown in Figure 82. For the Mental sub-scale the novices experienced higher frustration than either the experts or the knowledgeable participants. For the Performance and Frustration sub-scales the novices experienced higher frustration than the knowledgeable participants. The novices clearly had to work much harder to solve the schedule disruptions than either of the other participant groups, which was expected. They also believed that they were performing more poorly than the other groups, which, while not surprising, was not true. Finally, the novices experienced significantly higher levels of frustration than the knowledgeable participants. The differential between the knowledgeable participants and the experts may have been reduced by the difficulty experts had transitioning from their current computer system to the CWSS, which was also verified in the verbal debriefing which took place at the end of the experiment and was not statistically significant. The differential between the novice and knowledgeable participants reflected the novices' lack of domain knowledge.

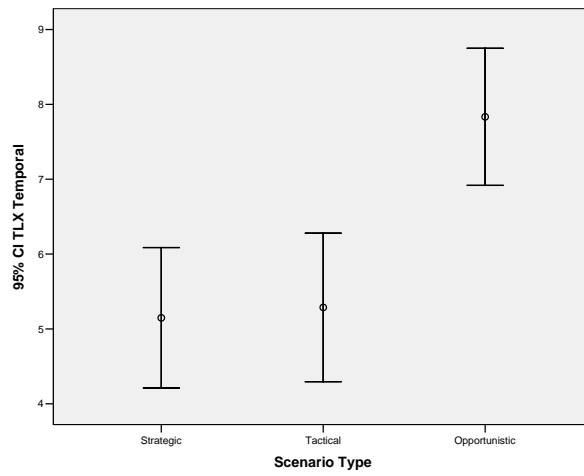
### *Contextual Control Mode*

While the CCMs were not shown to affect performance in the preliminary study, it did not assess the relationship between CCMs and workload sub-scales. A LMM was used here to analyze the impact of including CCM as a covariant for each workload sub-scale. Self-assessed CCMs correlate with the TLX performance sub-scale only,  $F(1, 28) = 23.054$   $p \leq 0.000$ , as shown in Figure 83.

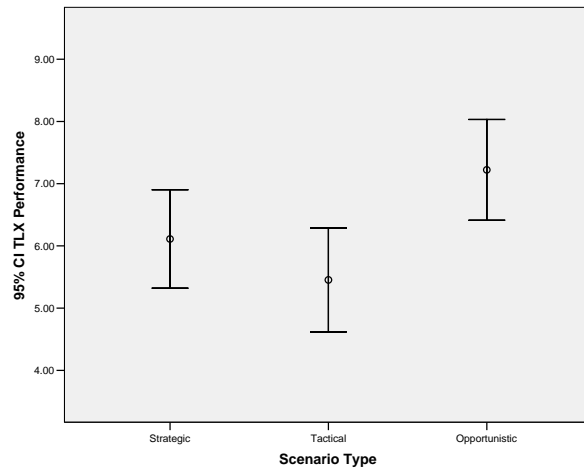
The preliminary experiment described in Chapter 3 indicated that transitions between CCMs were correlated with a higher level of frustration. A LMM was run which included CCM Transition as a covariate for each of the TLX sub-scales. Both the Performance  $F(2, 19) = 4.391$   $p \leq 0.050$  and the Frustration  $F(1, 41) = 7.062$   $p \leq 0.011$  sub-scales were found to be significantly affected, as shown in Figure 84. Again, participants who reported



(a) TLX Mental

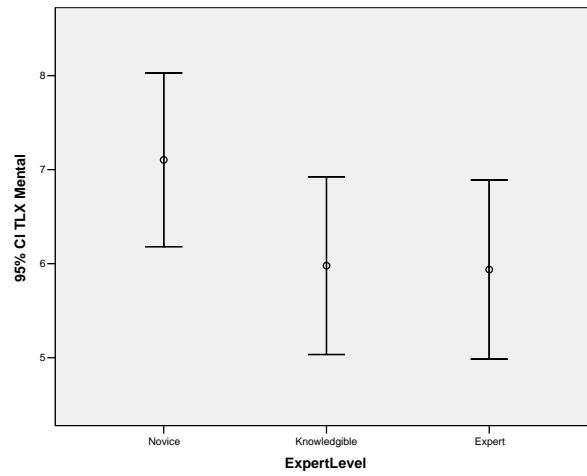


(b) TLX Temporal

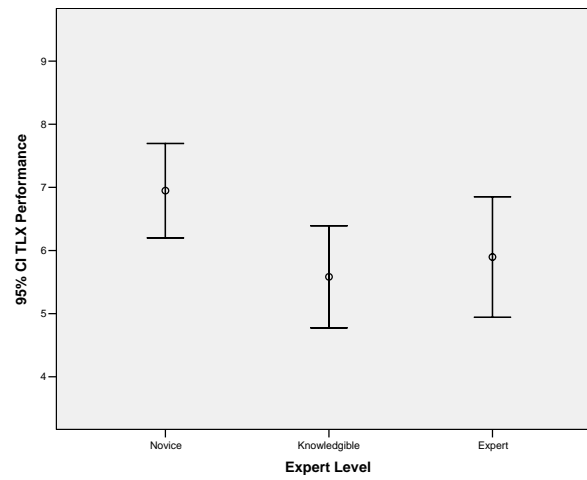


(c) TLX Performance

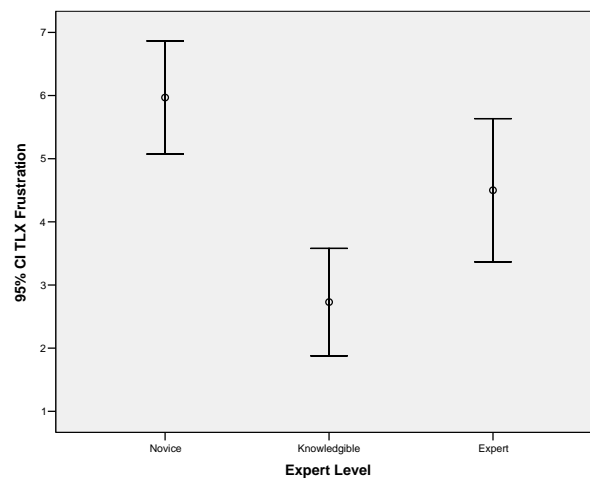
**Figure 81:** Effect of Scenario Type on Workload



(a) TLX Mental

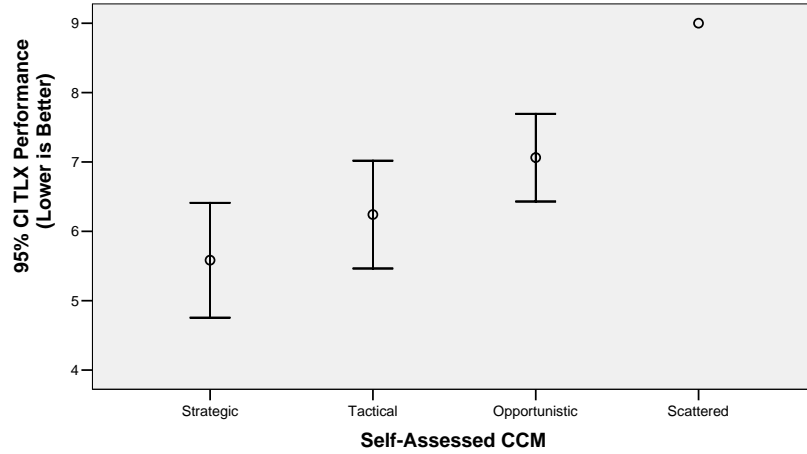


(b) TLX Performance

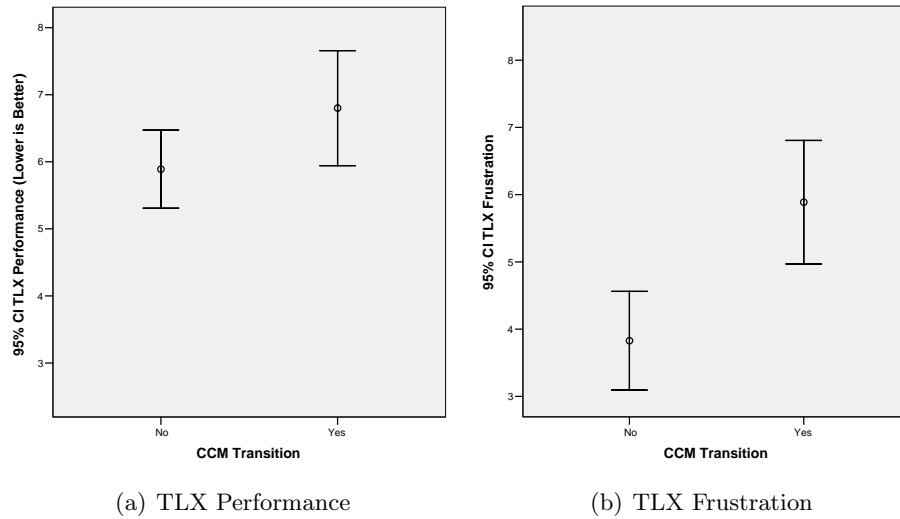


(c) TLX Frustration

**Figure 82:** Effect of Expertise on Workload



**Figure 83:** Perceived Performance by Self-Assessed CCM



**Figure 84:** Effect of CCM Transition on Workload

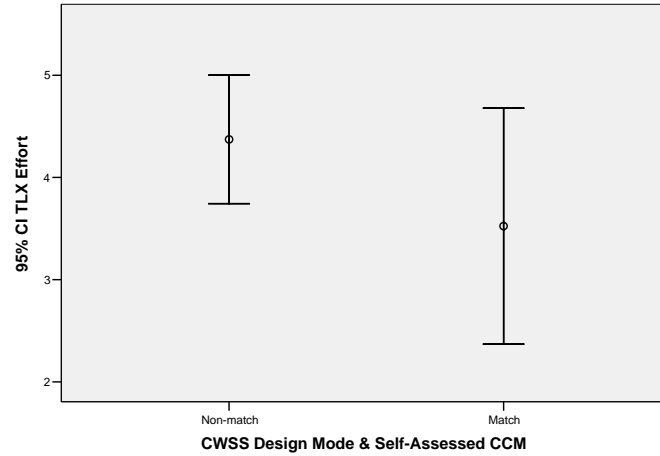
transitioning between CCMs indicated increased frustration and decreased performance. Interestingly, the participant's perceived performance decrement associated with the reported CCM transition reflects an actual performance decrement as shown earlier in Figure 80.

#### *Matching CWSS DM Cases*

As no significant performance differences were found between cases where the operational CCM and CWSS DM matched, differences in workload provide a more complete understanding. A LMM was used to analyze the effect of matching and non-matching cases on workload. The results are summarized in Table 12. No significant differences in workload

**Table 12:** Significance Level Summary

		TLX Sub-scales				
		Mental	Temporal	Performance	Effort	Frustration
Matching Scenario Type	$p \leq$	0.343	0.515	0.857	0.546	0.845
Matching Self-assessed CCM	$p \leq$	0.401	0.967	0.339	0.036	0.490

**Figure 85:** TLX Effort by Match Status of CWSS DM and Self-assessed CCM

were found for cases where the CWSS DM matched the Scenario Type. A significant difference was found in the Effort sub-scale in cases where the CWSS DM matched participants' self-assessed CCM. In cases where the modes matched, participants reported lower levels of required effort than in cases where their operational CCM did not match the CWSS DM.

#### *Workload Analysis Summary*

Workload showed much greater variability than performance. Scenario Type, Expertise, CCM transitions and matching CWSS DM were all shown to significantly affect some aspect of workload. Findings from the preliminary experiment of CCM transition on the frustration and perceived performance sub-scales were repeated. Interestingly, although perceived performance had no relationship to actual performance, there was a significant linear relationship to self-assessed CCM.



**Table 13:** CWSS Configuration Functions

	Viewers		
	Case	Solution	Evaluation
Organizers	Case	Review Case Information	
	Solution	Review Solution	Evaluate or compare solutions
	Spare AC	Look for spare aircraft for specific case	Look for spare aircraft to modify solution
	Schedule	Find additional schedule information and ways to solve case	Look solution component alternatives

### 7.2.3 CWSS Usage

The CWSS usage was recorded to analyze any significant changes an individual's CCM, the CWSS DM, an individual's expertise, or the scenario type; usage is described here by the amount of time spent in each CWSS configuration.

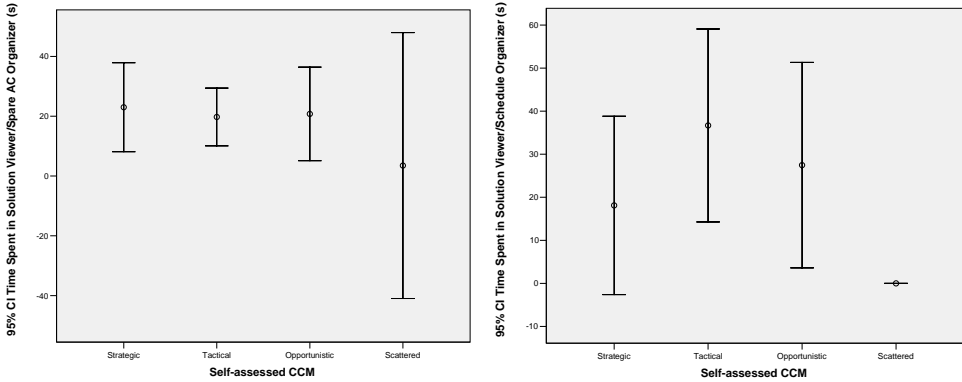
The CWSS was organized such that only a single viewer and a single organizer could be visible at a time. Accordingly, there were 16 possible CWSS configurations, only some of which were useful to the user, as shown in Table 13. For example, the configuration with a Solution viewer and Case organizer serves no purpose and is not of interest. A LMM was used to analyze the time spent in each configuration, where the CWSS DM, Expertise, and Scenario Type were modeled as factors and self-assessed CCM was modeled as a covariant. The results are summarized in Table 14, where the configuration of the tables mirrors the configuration of Table 13.

#### *Self-assessed CCM*

Only two configurations were significantly affected by the participants' self-assessed CCM: the Solution Viewer/Spare Aircraft Organizer and the Solution Viewer/Schedule Organizer, as shown in Figure 86. The difference in time spent in each configuration was primarily driven by the scattered CCM.

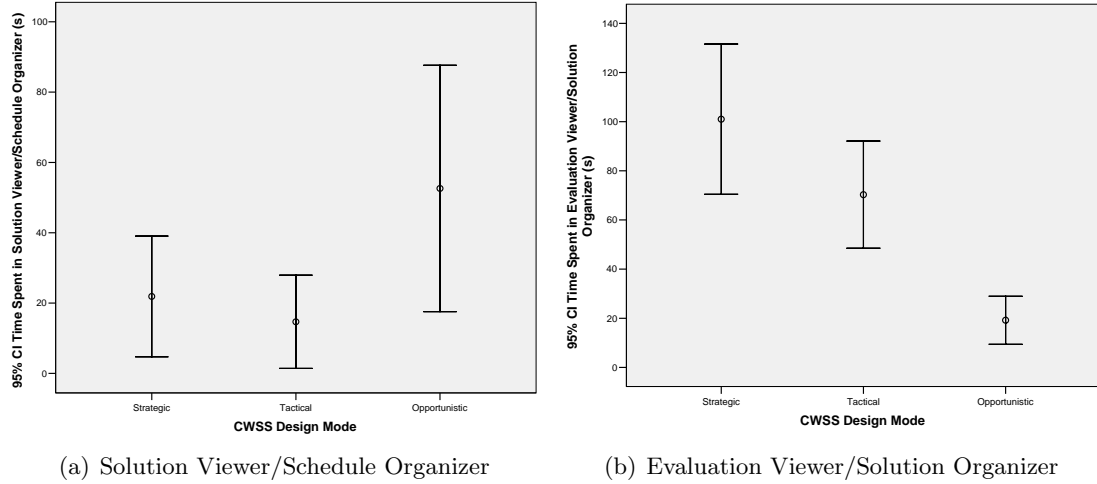
**Table 14:** Significance Level Summary for Time Spent in Each CWSS Configuration

(a) Self-Assessed CCM				
Organizers	Viewers			
		Case	Solution	Evaluation
	Case	0.400		
	Solution		0.133	0.180
	Spare AC	0.631	<b>0.019</b>	
	Schedule	0.544	<b>0.023</b>	
(b) CWSS DM				
Organizers	Viewers			
		Case	Solution	Evaluation
	Case	0.366		
	Solution		0.331	<b>0.001</b>
	Spare AC	0.450	0.627	
	Schedule	0.423	<b>0.039</b>	
(c) Expertise				
Organizers	Viewers			
		Case	Solution	Evaluation
	Case	<b>0.044</b>		
	Solution		0.726	<b>0.009</b>
	Spare AC	0.846	0.811	
	Schedule	0.476	0.608	
(d) Scenario Type				
Organizers	Viewers			
		Case	Solution	Evaluation
	Case	0.113		
	Solution		<b>0.040</b>	0.106
	Spare AC	0.231	0.069	
	Schedule	<b>0.019</b>	0.061	



(a) Solution Viewer/Spare Aircraft Organizer (b) Solution Viewer/Schedule Organizer

**Figure 86:** Effect of Self-assessed CCM on CWSS Configuration Time



**Figure 87:** Effect of CWSS DM on CWSS Configuration Time

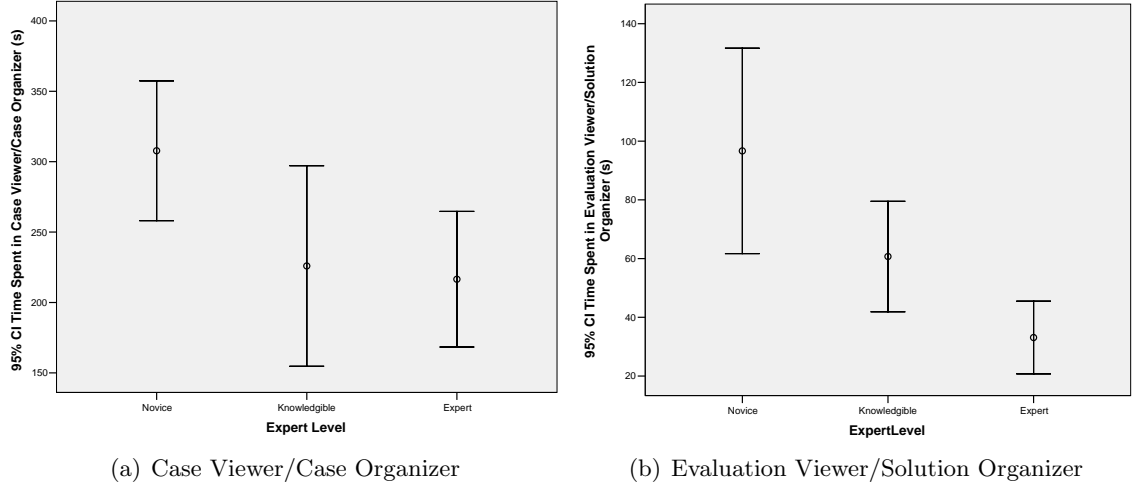
#### *CWSS Design Mode*

Two configurations were significantly affected by the CWSS Design Mode: the Solution Viewer/Schedule Organizer and the Evaluation Viewer/Solution Organizer, as shown in Figure 87. Participants using the strategic and tactical CWSS DM spent less time in the Solution Viewer/Schedule Organizer configuration than those using the opportunistic CWSS DM. Participants using the opportunistic CWSS DM spent significantly less time analyzing or comparing solutions in the Evaluation Viewer/Solution Organizer than in either the tactical or strategic CWSS DMs. As the opportunistic CWSS DM was designed to minimize the amount of time users needed to spend analyzing the solutions and the functionality to compare was not available, this result was expected.

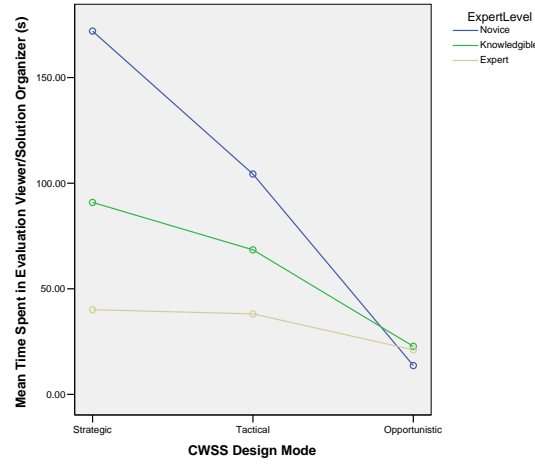
#### *Expertise*

Two configurations were significantly affected by participant experience level: the Case Viewer/Case Organizer and the Evaluation Viewer/Solution Organizer, as shown in Figure 88. The novices spent significantly more time trying to understand the problem in the Case Viewer/Case Organizer configuration than either the experts or knowledgeable participants. Similarly, novices spent significantly more time evaluating/analyzing solutions in the Evaluation Viewer/Solution Organizer than the experts or knowledgeable participants.

Both Expertise and CWSS DM significantly impacted the time spent in the Evaluation



**Figure 88:** Effect of Expertise on CWSS Configuration Time

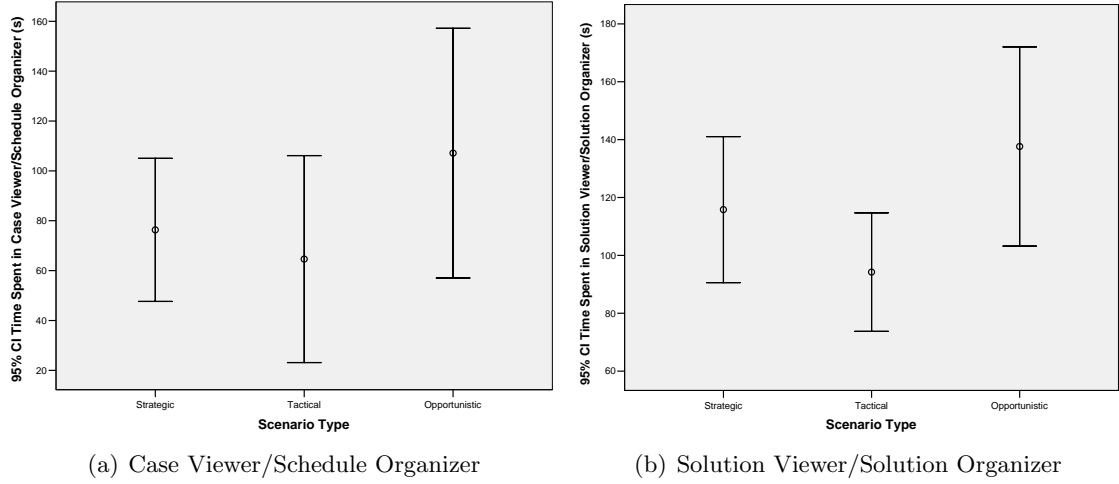


**Figure 89:** Effect of CWSS DM and Expertise on CWSS Configuration Time

Viewer/Solution Organizer configuration. Figure 89 shows the interaction between the CWSS DM and expertise. The more experience an individual had, the less the CWSS DM impacted the time spent evaluating and comparing solutions.

### *Scenario Type*

Two configurations were significantly affected by scenario type: the Case Viewer/Schedule Organizer and the Solution Viewer/Solution Organizer, as shown in Figure 90. In the Case Viewer/Schedule Organizer, the opportunistic scenario type resulted in significantly more time looking at the schedule upon case evaluation than with the tactical scenario type. In the Solution Viewer/Solution Organizer, no significant pairwise differences were found,



**Figure 90:** Effect of Expertise on CWSS Configuration Time

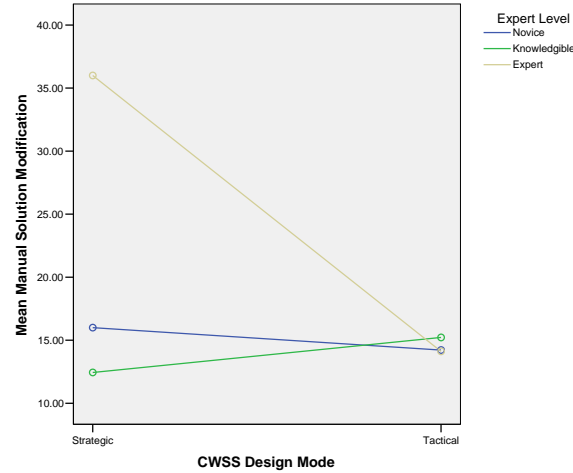
although there was an overall significant effect; it appears more time was spent in the strategic and opportunistic cases trying to understand the solutions.

#### *Manual Solution Modification*

In addition to the seven main configurations of interest, there were several focus areas which were separate windows and which could be opened in any CWSS configuration. These focus areas include: Manual Solution Modification focus area, the Solution Generation Assistant, the Problem Pad, and the Execution Verification focus area. The Manual Solution Modification focus area was considered to be the most important, as it would show how much time (in the tactical and strategic CWSS DM) the participants spent modifying a given solution. A LMM was used to analyze the time spent in the Manual Solution Modification focus area. Expertise was found to have a moderately significant  $F(2, 26) = 2.910$   $p \leq 0.072$  effect, and the interaction between CWSS DM and Expertise was significant  $F(2, 26) = 4.714$   $p \leq 0.018$ , as shown in Figure 91. Experts spent significantly more time modifying solutions in the strategic mode than the novices or knowledgeable participants.

#### *Usage Analysis Summary*

None of the independent variables affected the usage substantially. Time spent in the evaluation and comparison configuration was driven primarily by expertise and CWSS DM. Time spent trying to understand the case was much higher with the novices than the experts



**Figure 91:** Effect of CWSS DM and Expertise on Manual Solution Modification Time

or knowledgeable participants. Time spent modifying solutions was higher by experts in the strategic CWSS DM than by other participants or CWSS DMs.

#### 7.2.4 Analysis of Final Run

During the final run of the experiment participants were instructed to choose whichever CWSS DM form they wished and, if they chose, to switch between modes. The final scenario consisted of three separate aircraft and flight related problems which was comparable to the opportunistic scenario types used in the first nine runs. All but one of the participants initially chose to work in the strategic CWSS DM; the remaining participant chose to work with the tactical CWSS DM. Two of the participants subsequently chose to switch to the tactical CWSS DM. 44% of the participants chose the CWSS DM that matched their self-assessed CCM.

Performance on the final run was also analyzed to determine if performance improved when the participants used the CWSS DM that matched their self-assessed CCM, using an independent t-test. No significant difference was found. An independent t-test was also used to determine if there was any performance difference between individuals operating in the strategic or tactical mode (the only two reported modes for the final run). No significant differences were found.

As performance was uniformly high in the final run, the same analyses were also run

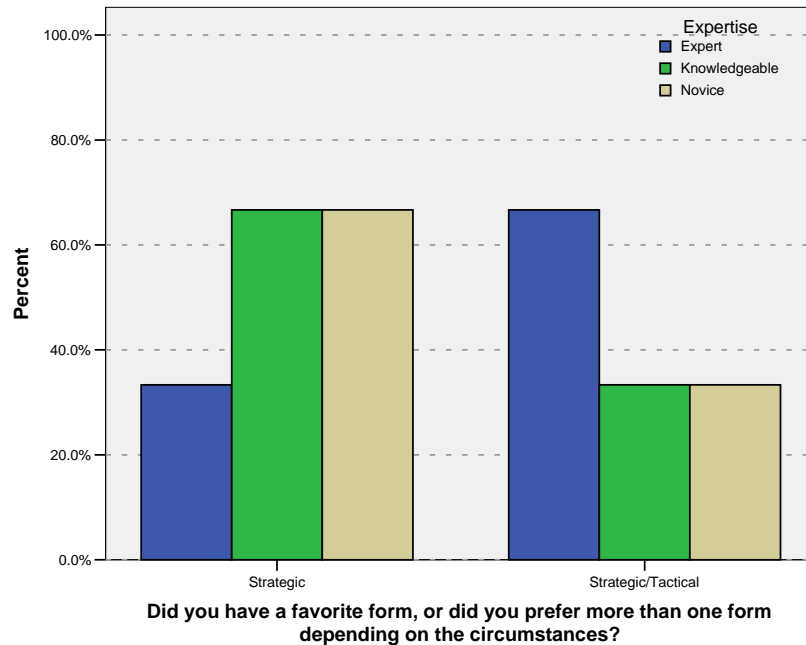
for each of the workload sub-scales to provide additional insight. No significant differences were found for any of the TLX sub-scales between cases where the participant's CWSS DM matched their self-assessed CCM. Overall effort was found to be marginally higher in participants who reported operating in the tactical versus strategic CCM,  $t = -2.487$   $p \leq 0.072$ .

### 7.2.5 Usefulness

After completing all the experimental runs, the subjects were asked to comment on the usefulness of the CWSS. Participants were asked to rate the overall usefulness on a 7 point scale. 67% reported that the CWSS was *Very Useful* and 33% reported that it was *Somewhat Useful*. The expert participants were then asked, "If the CWSS were available to you, would you use it?" Two of the participants responded *Yes* and the other one responded *Maybe*. Participants indicated that they liked having the computer provide them with a basic solution structure which they could then modify to meet their specific needs. Participants also reported that they liked the graphical representation of feedback about the impact of the different solutions. The expert participants were also asked, "Do you feel you would be more productive if given a final version of the CWSS?" Two of them responded *Possibly* and one responded *Yes*.

As the participants were unaware of the theory underpinning the design of the different CWSS DMs, the participants were asked to give their own opinion about how they could envision using the different forms of the CWSS under different circumstances. When the participants were asked, "Did the different CWSS forms make sense, i.e., could you imagine how one might be more useful in certain circumstances?" all but one of the participants answered *Yes* or *Maybe*. One novice participant commented, "Organization of [the] information was different. Plus, the ability to filter through solutions enabled me to operate the tool differently. The info seemed more readily available in the green [tactical] and orange [strategic] form."

Participants were then asked if they had a favorite CWSS DM and if they preferred one more than another depending on the circumstances. Figure 92 breaks down their responses



**Figure 92:** Participant Favorite CWSS DM

by expertise. All of the participants preferred either the strategic or a combination of the tactical and strategic CWSS DM. Participants were asked to explicitly list the circumstances under which they would prefer each CWSS DM. Their responses are summarized below:

#### **Strategic**

- Under heavy time constraints
- When faced with a GDP
- “When problem requires [a] very complex solution”
- When there are multiple viable solutions, where the implications are different

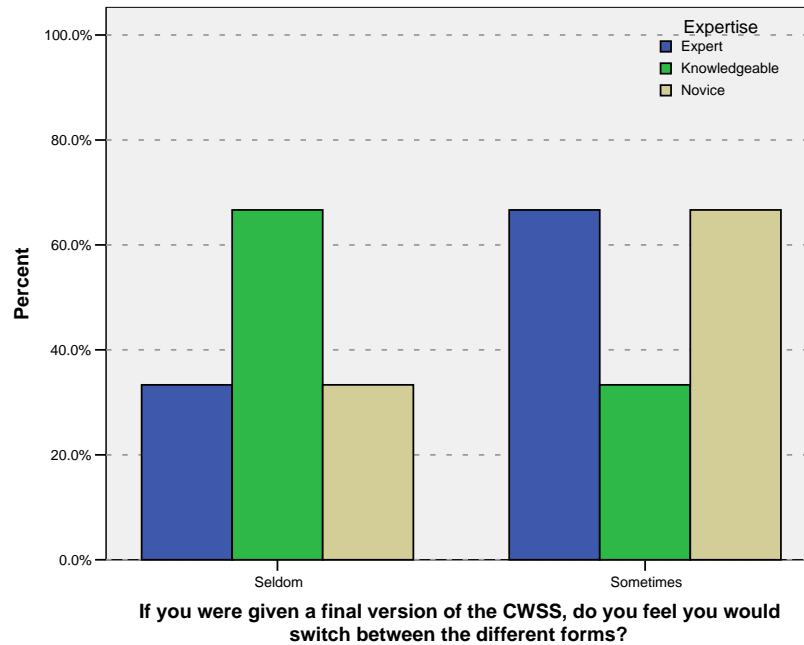
#### **Tactical**

- Under heavy time constraints
- When there is ample time to seek out the best solution
- When choices in the strategic CWSS DM overwhelm the user
- When operating under hard constraints, such as the number of spare AC, etc.
- Straight-forward, but not easily generated solutions

#### **Opportunistic**

- Easy solutions when computer generated solutions are not needed
- When there is time for manual solution entry
- “For solving relatively simple problems when you can easily see a solution without needing the pre-generated solutions as guides”
- Training





**Figure 93:** Participant Transition Likelihood

Participants were asked if they felt they would be likely to transition between CWSS DM if allowed to do so. Most felt that they would only use the strategic mode, and would deviate from that mode if circumstances warranted. However, this assertion was not borne out by their actions in the experiment's final run. Participants indicated that they would switch to the opportunistic mode if the solution was straight forward and they were not pressed for time. Participants indicated that they would switch to the tactical mode if they wanted a more simplistic set of suggestions.

Participants were asked if the features of the CWSS were easy to remember. 67% indicated that the memorability of CWSS features were *OK* and 33% responded *Easy*. Participants were also asked if the CWSS was easy to learn. Only one participant, reported that the CWSS was *Difficult*, while all of the expert and two of the knowledgeable participants indicated that it was *OK*. The remaining participant found the CWSS *Easy to learn*.

As the participants received only an hour of training, they were asked to rate the training they received prior to the experiment. All but one novice participant rated their training as either *Adequate*, *Fairly Well*, or *Very Well*. Participants were asked how much time would be needed to adequately train someone to use the CWSS, and they responded that between

**Table 15:** CCM Descriptors

Original Name	De-identified Name
Strategic Control	S-Control
Tactical Control	T-Control
Opportunistic Control	O-Control
Scattered Control	SC-Control

6-8 hours would be needed for adequate training.

### 7.2.6 CCM Measurement

This experiment used two different methods to assess the participant's CCM. The first method was very similar to the method used in the preliminary investigation discussed in Chapter 3: a 10 point scale that participants used to self-assess their CCM based on a set of CCM definitions given (see pg. 232). Unlike the first study, this study altered the names of the CCMs to minimize any associated connotations, as shown in Table 15. This measure is referred to as the self-assessed CCM.

The second method used an indirect composite measure of CCM by asking the participants to answer eight multiple choice questions which correspond to eight aspects of the CCMs as described by Hollnagel. Each question had choices corresponding to a specific CCM. There are two intended advantages to the indirect composite method: 1) it may provide greater level of understanding and 2) may also provide a more robust measure of CCM as no single aspect of CCM will dominate its selection. To create a single CCM measure, a simple additive composite score was computed by assigning 1 point to all answers which corresponded to a scattered CCM, 2 to opportunistic, 3 to tactical and 4 to strategic.

A Spearman rank-order correlation was computed for all of the individual questions and the composite score against the 10 point CCM scale. The results are summarized in Table 16. All of the questions had a significant correlation to the self-assessed CCM, except for Question 5, "How much of your past experience did you take into consideration?" The composite measure also had a significant correlation to the self-assessed CCM scalar measure  $r_s = -0.672$ ,  $p \leq 0.001$ , as shown in Figure 94. Figure 94 also shows that the composite score was less likely to classify an individual as being in a strategic CCM than the direct

**Table 16:** CCM Descriptor Alteration

Question	Correlation $r_s$	Significance
After completing an action how did you evaluate its effect on the system?	-0.430	0.000
Overall, would you say that you (had enough time)	-0.501	0.000
Would you say that you felt (pressed for time)	-0.465	0.000
How many different goals were you considering?	-0.407	0.000
How much of your past experience did you take into consideration?	-0.159	0.182
How far into the future did you evaluate the consequences of your actions?	-0.660	0.000
Which best describes your mode of execution?	-0.450	0.000
How would you describe the way you chose what actions to do when?	-0.338	0.000
Composite Measure	-0.672	0.000

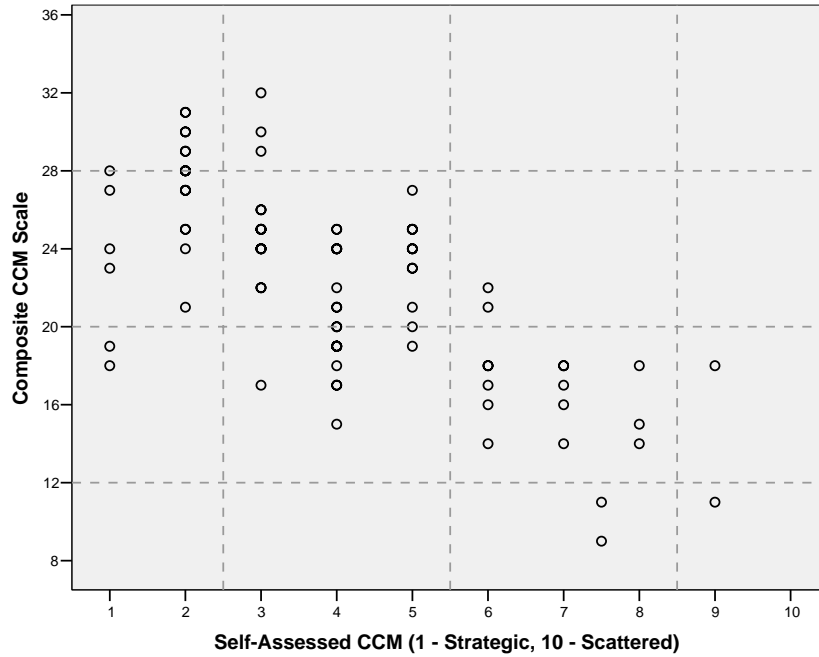
scale method.

### 7.3 Discussion

This experiment attempted to determine the effectiveness of providing users with a support system which was specifically designed to support their operational CCM. Specifically the evaluation sought to answer the six questions noted at the start of this chapter as discussed in the following sections.

#### 7.3.1 Was participant performance higher and the workload lower when the CWSS Design Mode matched the participant's operational CCM?

Two types of matches were considered in this analysis. The first type matched the CWSS DM with the scenario type which was intended to require a corresponding CCM. The analysis of performance and workload differences for cases using this type of match was inconclusive. No statistical differences were found for performance or any workload sub-scale. The second type matched the CWSS DM with the self-assessed CCM. Here again, the analysis of performance proved to be inconclusive. An analysis of workload, however, did reveal a significantly lower level of effort required for cases where an individual's self-assessed CCM matched the CWSS design mode. No other variables significantly affected the TLX Effort sub-scale. Participants reported significantly lower levels of effort to achieve



**Figure 94:** CCM Measurement Correlation

what was essentially the same level of performance when using a CWSS DM which matched their CCM.

Overall, participant performance was good. In all scenarios performance was significantly better than the default solution. Of the variables of interest in this study, only the CWSS DM showed a marginally significant effect on performance. Performance in the tactical DM was marginally better than performance in the opportunistic DM, but statistically no different from the strategic DM. The lack of a performance difference between the strategic DM and the opportunistic DM is interesting because the majority of participants indicated that, if given the option, they would prefer to use the strategic DM or some combination of the tactical/strategic DM. The only other variable which significantly affected performance was CCM transitions. Performance was significantly lower when participants reported transitioning between CCMs than when they did not transition.

Unlike performance, none of the workload sub-scales was significantly effected by CWSS DM. Workload was significantly affected by Scenario Type, Experience and Self-assessed CCM. Mental workload was significantly affected by the Scenario Type and Expertise. Opportunistic scenarios were significantly more mentally taxing, possibly because they included

a greater number of distinct disruptions. Novices also reported significantly higher mental workload, which was expected as they had no prior knowledge of the domain. Temporal workload was significantly impacted by the Scenario Type; the opportunistic scenarios were rated as having a significantly higher temporal component. Again, this is expected as the opportunistic scenarios had more distinct disruptions, which required distinct solutions to be generated, analyzed and entered.

Frustration was significantly effected by the participant's experience level and their reported CCM transitions. The experts were significantly more frustrated than the knowledgeable participants. In this case the experts found the transition to the CWSS frustrating, as the information they were seeking was organized differently than they were used to. We also found in both evaluations that participants reported significantly greater levels of frustration when they reported transitioning between CCMs.

The TLX Performance sub-scale was significantly effected by Scenario Type, Expertise and Self-Assessed CCM. The opportunistic scenarios were rated as being significantly more frustrating than the tactical, again probably because of the higher number of distinct disruptions causing participants to believe that they did not do as well as they had in other scenario types. Novices also reported that their performance worse than the knowledgeable and expert participants. Perceived performance was significantly effected by Self-assessed CCM. Perceived performance was highest in the strategic CCM and lowest in the Scattered CCM. What is interesting to note about the TLX Performance sub-scale is how it differs from actual performance.

### **7.3.2 Was CWSS usage affected by scenario type, CWSS DM, or self-assessed CCM?**

The CWSS DM and Expertise significantly affected the amount of time participants spent evaluating or comparing their solutions. It was interesting to find that the expert participants spent a consistent amount of time evaluating and comparing their solutions regardless of the CWSS DM. This may be a sign that the experts' internal ability to evaluate and compare solutions was much more developed than the other participants, allowing them to use the comparison and analysis tools solely for confirmation. Expertise also significantly

impacted the amount of time that participants spent trying to understand the disruptions, as novices spent much more time in the Case Organizer/Case Viewer configuration. This may also be an indication that the knowledgeable and expert participants were much more quickly able to match the current disruption to previous experience. The interaction between Expertise and CWSS DM was also a significant predictor of the amount of time participants spent modifying solutions. In the strategic DM, experts spent far more time modifying solutions than either of the other participants or than they did in the tactical DM. CWSS usage did not appear to be overly impacted by the participant's self-assessed CCM, as both configurations where self-assessed CCM corresponded to significant time differences were driven by the rare scattered CCM.

### **7.3.3 In the final run, did the participants choose the CWSS mode which was most appropriate for the situation, that matched their CCM and/or that maximized their performance?**

Almost all of the participants choose to use the strategic DM in the final run, despite the fact that only 44% reported operating in the strategic CCM and contrary to the intention that this scenario demand opportunistic behavior. No differences were found in performance or workload for individuals operating in the different CCMs, with the exception of effort. Effort was significantly higher in participants in operating in the tactical CCM. Participants in the final run were, however, hesitant to change design modes. This may simply be a reflection of the novelty of the system and the concept of changing modes to match the circumstances. Overall, the participants in the final run performed very well, statistically better than on the other comparable scenarios in runs 1-9. It is difficult to say if this is because they were allowed to choose their own DM or if it was a reflection of the ease of the underlying scenario disruptions.

### **7.3.4 How do we measure CCM?**

This study proposed two different methods to measure CCM: a single 10 point scale, which the users directly reported their CCM based on definitions provided; and a composite scale created from eight indirect questions. The two measures of CCM correlated highly. Only one of the 8 questions included in the composite score was shown not to correlate. This

question asked the individuals how much of their past experience they were considering: The experts uniformly answered that they were using all of their experience. Such a composite measure may be a more robust measure of CCM because it provides a greater understanding of the different aspects of CCM and is less susceptible to individual bias or an individual's interpretation of the relative importance of the multiple dimensions in the definitions provided. Figure 94 shows that the composite CCM score classifies far fewer individuals as having a true strategic CCM than the self-assessments, and considering the nature of the scenarios is much more likely to be the case.

One interesting finding of these evaluations was the high correlation between the TLX performance ratings and self-assessed CCMs. Instead of correlating with actual performance, none of the measures which impacted the perceived performance impacted actual performance. This opens the question: what do people report when asked to state their perceived performance and assuming that particular CCM correspond to degraded performance? Perhaps participants are actually reporting their CCM when asked to rate their performance.

### **7.3.5 Did the design process produce a CWSS whose modes met user's needs?**

Overall, participants reported that the CWSS was useful to them, and that if given a final version of the tool, they would most likely use it. Participants also commented favorably on aspects of the CWSS' usability such as learnability, memorability, errors and efficiency.

The design process produced a CWSS with three distinct modes corresponding to the support anticipated for individuals operating in three CCMs. The design was successful in supporting individuals operating in a Tactical and Strategic CCMs, as borne out by the user's description of which mode was most appropriate for specific contexts. Unfortunately, the design does not seem to have met the needs of the Opportunistic CCM.

The Opportunistic CCM is defined as a cognitive mode where one's next action is chosen based on the current context alone, i.e. independent of future goals and often on only the most salient features of the context. Planning and anticipation are often limited due to limitations in resources and/or limited time. To support this CCM the opportunistic

design mode to simplify the solution creation process by removing the computer suggestion functions. Having a manual solution creation was intended to reduce the amount of iteration required to understand and modify any automated solution. To aid with solution creation a solution completion function was added. Additionally, a default solution was automatically created upon case entry which provided information about case impact, as was an easy-to-understand default solution which they could modify or use (if time required an extremely quick solution). The opportunistic DM also restricted the number of solutions available to one, which eliminated any comparison and was meant to facilitate using the evaluation viewer as a double check on their own instincts.

Unfortunately, the participants did not see the merits in the opportunistic DM. Their primary complaint was that it took much longer to create solutions with it than the other DMs. The novices also complained that it did not help them find solutions. The difference in the amount of time required to generate a good solution, i.e. one better than the default, led to a discrepancy under what time constraints participants stated that they would find each CWSS DM appropriate.

There are many reasons which may explain the discrepancy regarding CWSS DM under time constraints. First, the participants were given artificially tight time constraints and only had limited experience using the CWSS; in the case of novices this was exacerbated because they also had very limited experience solving schedule disruptions. Consequently, the manual solution creation probably seemed much more cumbersome than the solution generation functionality provided by the tactical and strategic DMs. Secondly, the manual solution creation completion functionality could be improved upon to make solution creation faster and less confusing. The function required that the user enter only the “top” level of a solution and then allow the system to propagate any subsequent delays, or cancellations. The concept of “top” level solutions proved to be difficult for the novices to grasp. Further, the experts had a hard time remembering that the system required user input to complete this propagation (as their normal systems automatically propagate delay). Lastly, the disruptions presented in this evaluation were fairly straight forward. Given a more unusual problem, the system may have not been able to develop the solutions sought, which might



have altered the participant's perception of the CWSS.

Future iterations of the CWSS should incorporate a number of design changes. First, they should allow the user to create pieces of a solution and then combine them because, while the solution creation tool proved useful way to work with one aircraft at a time, it became cumbersome to work with flights from multiple aircraft. Secondly, they should add greater flexibility to the solution complete function and allow the user's to target the aspects of the completion that they wish. Third, they should focus on making the solution creation process, not just the solution evaluation process, much more efficient, perhaps with the use of some drag and drop functionality. Finally, they should also allow the system to keep two solutions at any time; the first solution would be the default solution, against which the user could compare subsequent solutions.

#### ***7.4 Usefulness of Designing for Multiple CCMs***

In light of the analysis of the data collected no conclusive evidence is found to support the hypotheses that designing for multiple CCMs improved performance either in cases where an individual's CCM matched the CWSS DM or of the individuals operating in an opportunistic CCM. Unfortunately, the absence of evidence of any effect of CWSS DMs on participant performance does not allow any definitive conclusion to be reached as to why no performance improvements were found. It is not possible to distinguish between the true absence of an effect of the CWSS DMs and the possibility that the evaluation and metrics did not adequately capture the underlying construct. For example requiring the individuals to complete tasks within a 10 minute window may have caused artifacts, obscuring the true performance. Similarly, as no external validation was found for self-assessed CCMs perhaps using this measure as a foundation for analysis may have masked the true underlying phenomenon. As no evidence was found for the hypothesis, it is useful to consider alternative uses for the incorporation of multiple CWSS DMs and their applicability based on the evidence. First, in light of the relatively high performance across all operational CCMs, the goal of future CWSS might instead be to maintain a high level of performance while reducing workload. Second, the goal might be to minimize the level of workload associated

with each operational CCM so that under high task loading conditions individuals are able to use higher-level CCMs (Strategic/Tactical) while maintaining a lower level of effort. As the only difference in either performance and work load for matching cases were in the TLX-Effort sub-scale it might be possible to achieve the second goal of minimizing workload associated with higher level CCMs by using CWSS DMs tailored for specific CCMs.

## **7.5 *Summary***

To summarize, this evaluation had several interesting findings. The first was that performance was independent of the participant's Self-assessed CCM, as predicted and as found in the preliminary study. Performance was, in fact, independent of almost all of the other predictors and covariates, the primary exception being CCM transitions. Again, as in the previous study, participants who reported transitioning between CCMs also reported decreased performance, increased frustration and actually performed worse. The second interesting finding was that perceived performance actually varied linearly with a participant's self-assessed CCM, but not with the actual performance. This raises the question of what the TLX Performance sub-scale is actually measuring. The third interesting finding is the lower level of effort participants reported when using the CWSS DM that matched their operational CCM. Finally, the design process did successfully create a CWSS with DMs which support specific CCMs, but it is unclear if the inclusion of these DM is useful to CWSS design as no performance improvements were found.

## CHAPTER VIII

### CONCLUSION

This thesis demonstrated three distinct contributions. First, it provided a theoretical foundation relating the high level constructs of contextual control modes to engineering design. Second, it formulated a method of designing cognitive work support systems using the CCMs. Third, it demonstrated these capabilities and benefits of CCM in a relevant domain. Each of these contributions will be discussed in the following sections.

#### ***8.1 Theoretical Foundation Relating CCM to Engineering Design***

The thesis provided a theoretical foundation for relating CCM to engineering design. It began by examining the evolution of human performance modeling from the initial stimulus-response methods introduced during the industrial revolution to model factory worker productivity, continued by discussing the information processing model where human cognition was modeled as a series of actions carried out in a predefined order, and ended with the concept of cognitive control whereby cognition is not considered a context-free mental process but modeled as an individual's ability to maintain control under varying contexts and to counter the effects of disturbances. Specifically, "the control of the activity is determined by the sequence of cognitive goals rather than by the inherent structure of the activity; the sequence of cognitive goals is, in turn, determined by the context: the environment and the previous development" [42].

Observation of AOMs revealed a wide variety of approaches to the overall task of schedule adherence, including not just how to make a decision, but also which decisions to make, which patterns of communication, coordination, and information seeking to employ, and when to apply these actions. It was clear that the AOMs had different methods of operating, some of which made their current support systems at best awkward to use and at worst ineffective.

A model was sought to explain and predict the overall pattern of activities observed.

The contextual control model proposed by Hollnagel is built on a great diversity of models of component actions, including judgment and decision making, and allows for many different patterns of behavior and many different ways of approaching a high level task, such as the problem solving tasks often involved with cognitive work. COCOM's model of cognition, with its definition of CCM, provides a framework under which different modes for a cognitive work support system can be envisioned to support each of the different CCMs. Supporting more than one CCM is important given the variety of patterns of behavior, including decision making strategies, that have been identified in the literature. Additionally, the ethnographic studies of AOMs corroborated the existence of a high level construct such a contextual control modes which could be readily identified and captured in work models.

## ***8.2 Design of a CWSS Using CCM in a Relevant Domain***

This thesis set out to design and evaluate a cognitive work support system for airline operations managers. The airline operations domain was chosen because of the current modernization efforts of the national air transportation network and because of the interest of expanding the use of optimization techniques in airline operations to aid day-of operations. As more responsibility for maintaining safe separation is given to pilots and more collaborative tools are developed to enable closer collaboration between airlines and air traffic control, the role of the airline operations managers will take on even greater significance. Additionally, the efficient and safe daily management of an airline is a complex cognitive task involving multiple individuals working in close coordination.

The support system sought to go beyond the functionality normally provided by a decision support system to aid in all aspects AOM's work from information acquisition through decision making to action execution. A review of the literature on decision making revealed an evolution from analyzing human behavior by breaking it into atomic behaviors such as judgement, attention, and decision making to attempting to situate these behaviors and their resultant meta-behaviors or patterns of activity or patterns of cognition. Recently, there had been much interest in and work to try to understand the role that context had on cognition and patterns of activity. Contextual features such as time constraints, information

availability, information certainty, past history, number of concurrent tasks, task goals, etc. were added to the more traditional list of lighting, temperature and ambient noise.

Research on the effect of contextual features on cognition and behavior lead to the cognitive control model of cognition which eliminated the idea that atomic behaviors are linked together in any specific manner. Hollnagel's model of cognitive control, the Contextual Control Model (COCOM) stated that the pattern of atomic behaviors is instead determined by context.

COCOM has three elements: a model of competence; a model of control and constructs. The model of control describes the degree of control an individual has over a situation as a continuum with one end where there is a high degree of control and the opposite end where there is little or no control. COCOM delineates four distinct CCMs along this continuum: strategic, tactical, opportunist and scattered. The model predicts that individuals operate in different locations along the continuum as they attempt to maintain control over dynamic situations. Breaking the continuum into CCMs, this movement translates insight into transitions between different CCMs. A preliminary evaluation was conducted to determine if CCMs could be measured and if they provided any additional insight cognitive work. The evaluation revealed that CCMs could be measured and the self-assessed CCM varied as predicted.

The first half of the thesis develops a design process which utilizes the CCMs as representing specific patterns of activity, thus specifying the design requirements. In the design process the following questions were posed and answered:

- How should a support system be designed to support a wide variety of behaviors?
- What are the important contextual features that influence CWSS?
- How do these contextual features affect behavior?
- What activities should the system aim to support?
- How should the work be apportioned between the human and the CWSS?
- How should the human and the CWSS interact?

The first question was partially answered by using CCMs as a framework to view the changes in the patterns of activity in response to context. Using CCMs the problem could be reframed as, “ how should a support system be designed to support the Strategic, Tactical,

Opportunistic, and Scattered CCMs?” Consequently, the process became more tractable as each CCM could be examined for insight and a determination could be made as to how best to support the range of behaviors described by each CCM.

The remaining questions and the specifics on how to support specific CCMs were answered in the development of a design process which modified the contextual design method as described by Beyer & Holtzblatt to incorporate support for each CCM and had the goal of supporting multiple CCMs by creating separate forms of the support system referred to as design modes.

The design process began with a series of contextual inquiries at four separate airlines and the creation of work models describing: information flow, the physical environment, artifacts, sequences and the culture. The work models captured not only the work, but often the context or CCM for which the model was appropriate. The work models illustrated inconsistencies between the current work practices and computer systems in use, and detailed how the work changed under the different CCMs, highlighting changes in patterns of communication, information seeking, collaboration and decision making strategies. The overall work performed by the AOMs at each airline was found to be very similar in terms of responsibilities and tasks, despite the differences in culture, computer systems and airline resources. The work models were used to answer the question about which activities the CWSS should support as well as identifying the contextual features that had an impact on the AOM’s pattern of activity. These features included the number of spare aircraft and crew available, the status of the national air space system, inclement weather, load factor and time of day.

The next phase in the design process examined the work models for design insights and implications. The work redesign and visioning process was modified to accommodate the CCMs and resulted in a set of three complementary vision diagrams and storyboards which establish how to integrate a CWSS into the work process to adequately support each CCM. The work redesign process posed and answered the questions about work apportionment and interaction by examining the work models for outstanding issues. Of particular interest were the concept of roles undertaken by the AOMs, the functions provided by the CWSS

and how those roles and functional requirements changed with context. The final phase of the of the work redesign and visioning process, the creation of storyboards, began to address the question of how the human and the CWSS should interact, as summarized in Tables 5, 6, and 7.

The final phase in the design process, the UED and prototype design, provided the remaining answers to the questions of functionality and interaction. The UED introduced the concept of *focus areas* each of which comprise a coherent set of functions supporting a single activity. The selection of focus areas defined the available functions. The work flow was created by defining links between the focus areas. Three complementary UEDs were created to correspond with the three CCMs. The UEDs had the additional feature of indicating how many different versions of the focus were required and which subset of CCMs had common focus versions, as shown in Figures 55-57. In the prototype creation each focus area was designed to meet the functionality and the information requirements unique to its corresponding specific CCM.

The resultant prototype was evaluated using nine participants in a controlled experiment intended to examine the effectiveness of the CWSS by testing to see if it improved the performance of users when their CCM matched the CWSS DM. Individuals used the CWSS set to a specific DM to minimize the impact on their airline in scenarios intended to demand different CCMs. The experiment examined performance, workload and patterns of activity, and had had several interesting findings. The first was that performance was independent of the almost all of the predictors and covariates including participant's Self-assessed CCM, with the exception of CCM transitions. As in the preliminary study, participants who reported transitioning between CCMs also reported decreased performance, increased frustration and actually performed worse. Second, perceived performance actually varied linearly with a participant's self-assessed CCM, but not with the actual performance, raising the question of what the TLX Performance sub-scale is actually measuring. Third, participants reported lower levels of effort when using a CWSS DM that matched their operational CCM. Finally, the design process did successfully create a CWSS with DMs which support strategic and tactical CCMs.

### **8.3 CCM Measurement**

Along with the ample literature describing the existence of multiple patterns of behavior, including decision making [22,49,49,73,75], the results of the ethnographic studies included in this thesis point to the existence of some higher level construct capable of describing an individual's pattern of activity and cognition. Following COCOM's model of control, this thesis has had some success defining and measuring the CCMs. Two separate studies have been conducted where CCMs have been measured. Those measurements have proven to have the requisite variability and to vary as the model would predict. For example, CCMs have been shown to correlate highly with time limits and self-assessed temporal workload. This thesis presented two methods for measuring CCMs: one direct single scale and one indirect composite scale. The measurements correlate highly. Both have a high degree of face validity and user acceptance. The composite measure may be a more robust measure of CCM because it provides a greater degree of diagnosticity by specifically inquiring after different aspects of CCM and is less susceptible to an individual's interpretation of the relative importance of the multiple dimensions of CCMs included in the definitions. In the end, no external validation of either self-assessed CCM measurement was found. Lack of external validation weakens usefulness of the measure as a true indication of cognitive state.

#### **8.3.1 Behavior Prediction**

A complete definition of the Contextual Control Model (COCOM) was provide in Chapter 2. COCOM's model of cognition predicted which contextual features were likely to invoke different patterns of behavior. Having used this model as a basis for design, let us now review the model and compare its predictions to the behaviors observed during both evaluations. The behaviors predicted by the model are listed in Table 2 on page 21.

##### *Strategic*

COCOM predicts that with a strategic CCM individuals will have several goals; has adequate time; select their next action based on their prediction of likely future events; has an elaborate evaluation. Additionally, the event horizon will be extended. Plans available



will be predefined, and the execution mode will be mix of subsumed and feed-back driven. While this description is appropriate for the behaviors observed in this study, there are some aspects which deserve further discussion. First is the amount of subjectively available time. The model predicts that individuals can operate in a strategic CCM if they have adequate time. Observations revealed that individuals need to feel that they have much more than adequate time to report being in a strategic mode. For example most individuals reported that they were not really in a strategic mode because they did not have enough time, even when they had 50% more time than they reported being adequate for operating in the tactical mode. Second, individuals also had a hard time distinguishing between strategic and tactical modes, often confusing the two and distinguishing only based on the time available. If they finished all evaluations they wanted with time to spare they were more likely to report being in a strategic mode. If they did not, then they would report being in a tactical mode. This is likely the reason that Figure 94 shows that the composite CCM score classifies far fewer individuals as having a true strategic CCM than the self-assessments.

#### *Tactical*

COCOM predicts that in a tactical CCM individuals will have several goals, adequate time and select their next action based on a procedure (trained or personal preference). They will have a normal evaluation of events, a normal event horizon; a standard set of plans from which they draw; and use feedback which compares the actual outcome to the expected outcome. Based on the observations and evaluations in this document, this is a plausible description of tactical behaviors. This is the standard behavioral pattern for AOMs when working with the sector, fleet and computer systems to which they are accustomed. Changing any of these parameters often pushes them into either the Strategic or Opportunistic mode until they can re-establish their procedures or personal preferences for the new situation.

#### *Opportunistic*

COCOM predicts that with an opportunistic CCM individuals will have one or two competing goals, feel that the time they have remaining is tight, select their next action based

on association to their current actions, have a concrete evaluation of events, have a narrow time horizon; and limited plans available, and use a feedback mechanism based on observation of the system instead of expected outcomes. The main behavioral differences from the model predictions were with the event time horizon and the plans available. Often the opportunistic mode resulted from lack of time and lack of information. AOMs who were operating in the opportunistic mode were aware that they lacked the time or resources to act as they wished and, consequently, often took more defensive actions, or actions that preserved the greatest number of future options. A classic example is the case of unplanned maintenance, where the problem is first reported to the AOM with little accompanying information and a very tight time horizon. AOMs often react by issuing a short delay to cover the diagnosis. They take this action even if the maintenance or gate agent hint that it could take much longer and are especially likely to do it if they are working multiple other issues at the time.

### *Scattered*

While the scattered mode was observed very rarely in the evaluation and observations, it was observed. COCOM predicts that individuals operating in the scattered mode will have a single goal, an inadequate amount of time, random selection of next actions, no event horizon or plans available, a rudimentary evaluation of events and a subsumed execution mode. Based on the few observations of this mode, this is an adequate characterization with two exceptions. The first exception is the number of goals. Based on these observations, the scattered mode could be characterized as the loss of all goals, and especially the loss of goals the user believes to be achievable. For example a student taking a test may begin the exam with two goals: answer as many questions as possible; complete the easy questions first. Once the student reviews the test questions, if the student does not believe that he can answer any question on the test, his number of goals has strunk to zero. If he is unable to find a new achievable goal he may enter a panic state, or a scattered CCM.

The second difference between the model and observations described previously is the idea that scattered is necessarily linked to inadequate time. While this is often the case, I

believe that sometimes an individual with adequate time may still enter a scrambled mode if they experience the loss of an achievable goal. For example, I observed an AOM enter a scattered mode while working a hurricane situation where he was responsible not only for canceling all of the flights to the affected airports, but also addresses all problems arising with flights in his geographic region of responsibility. I accompanied him to a briefing where he believed that he received instructions to cancel all flights into and out of airport X (there was a possibility of the hurricane hitting any of three stations) based on it having the highest probability of being directly affected by the hurricane. He left the briefing with multiple goals. The most critical of which was to cancel all of the flights into and out of airport X. Secondary goals included trying to minimize the impact of such cancelations on other airports and passengers and trying to preserve spare aircraft, etc. To try to meet all of these goals he attempted to use a DSS that had been recently introduced. He turned it on, programmed in all of the problem parameters and let it churn. It came back with an answer that did not make sense to him. He tried again. Same result. He tried again. Same result. He turned it off and decided to work the problem by hand. Considering the number of flights and aircraft involved, he knew this would take him several hours. It also meant dropping several of his goals, leaving him only one remaining – cancel all flights into and out of airport X. He got about 10 flights into a list of around 60 flights when his boss came over and asked what he was doing; why was he canceling flights to and from airport X? A short conversation followed where he was instructed to stop canceling flights and to reinstate several of the ones that he had canceled. In the AO environment, once canceled flights are never reinstated. Thus the AOM was left with no goals that he felt he could achieve. He spent the next minute standing up and sitting down in rapid succession, unable to determine what to do next. He had over 4 hours before the winds would be too high to fly.

### **8.3.2 Design**

Using the CCMs and an augmented contextual design process, a CWSS with multiple design modes was created and tested. The tactical and strategic design modes were successful

at supporting individuals. The opportunistic design mode was less successful in that it required significantly more time to create a solution than the other design modes, leading the users to characterize it as not useful for situations with short time horizons.

There are many reasons why the opportunistic design mode was less successful than the other two design modes. First, the participants were given artificially tight time constraints, and only had limited experience using the CWSS; in the case of novices this was exacerbated because they also had very limited experience solving schedule disruptions. Consequently, the manual solution creation probably seemed much more cumbersome than the solution generation functionality provided by the tactical and strategic DMs. Second, the completion functionality for the manual solution creation could be improved upon to make solution creation faster and less confusing. Third, the disruptions presented in this evaluation were fairly routine. Given a more unusual problem, the system may have not been able to develop the solutions sought, which might have altered the participant's perception of the CWSS. The following sections summarize each design mode.

Unfortunately, this thesis found no conclusive evidence to support the hypotheses that designing for multiple CCMs improved performance either in cases where individual's CCM matched the CWSS DM or improved performance of the individuals operating in an opportunistic CCM. This calls into question the usefulness of designing for multiple CCMs. Unfortunately, no definitive conclusion can be reached why no performance improvements were found, as the absence of evidence of any effect of CWSS DMs on participant performance does not necessarily mean that no effect existed. Further evaluation of the CWSS and the CCM measurement metrics is warranted to provide further evidence to corroborate or refute the current findings. An alternative goal for the use of multiple CWSS DMs based on CCMs would be to use CWSS DMs to minimize the level of workload associated with each operational CCM so that under high task loading conditions individuals are able to use higher-level CCMs (Strategic/Tactical) while maintaining a lower level of effort.

### *Strategic Design Mode*

The strategic DM supported users by requiring them to use the system to suggest solutions. The solution suggestion asked the users to specify the relative weighting or ranking of the solution parameters. It would then return the top five solutions based on the specified criteria and would inform the user if no additional solutions existed. The user could evaluate, compare, duplicate, delete or modify solutions. The strategic DM provided eight dimensions of solution evaluation, six of which could be displayed simultaneously according to the user's preference.

### *Tactical Design Mode*

The tactical DM supported users by providing the option to create a solution from scratch or to have the system suggest solutions. The solution suggestion required the users to specify the maximum and minimum solution parameters which would be acceptable. It would then return all solutions which met criteria, or the system would inform the user that no solutions met the criteria and if any other solutions existed. The user could evaluate, compare, duplicate, delete or modify solutions. The tactical DM provided five dimensions of solution evaluation.

### *Opportunistic Design Mode*

The opportunistic DM supported users by automatically generating a default solution to the problem and displaying its impact to them. Users had the choice of modifying the default solution or creating an original solution. If the user wished to create an original solution, they were required to manually generate it. It supported this behavior by including a function to propagate the resultant delays and to suggest flights which could help balance the fleet after cancelations. To minimize the time spent trying to compare multiple solutions, only one solution was kept by the system. Users could evaluate or modify this solution. The opportunistic DM provided four dimensions of solution evaluation.

## **8.4 *Future Work***

This thesis has focused on trying to better understand CCMs and to incorporate them into the design process. Much has been learned, but there are many questions and areas which this thesis did not answer or cover. Extending our understanding of CCMs should be a focus of future work.

### **8.4.1 From Individual to Collaborative Work**

The observations included in this thesis revealed that AOMs work in a very collaborative environment where they are in constant contact with colleagues both within the operations center and at stations around the globe. The scope of the prototype development however, was restricted to the creation of a CWSS for an individual AOM working in isolation. Future work should extend the CWSS to accommodate collaborative work with other AOMs and others such as maintenance coordinators, dispatchers, and ATM centers. This work should focus on how the introduction of collaboration impacts an individual's CCM, and conversely how CCMs affect the nature of the collaboration. Earlier in this thesis it was hypothesized that individuals in a strategic CCM might spend considerably more time communicating and collaborating, while opportunistic individuals might only communicate to gain very specific information or to inform others of decisions already taken.

The work should also focus on how CCMs generalize to groups or teams. How should team CCM be assessed? How does individual CCM impact team CCM, team performance or both? Is it better to have all individuals operating in a single CCM or to have some individuals in each category? Would it help for everyone to know the CCMs of their colleagues? Would it help for the team leader/manager to understand her teammates' or subordinates' CCMs? If everyone's individual CCM were known, could it be used to distribute workload?

### **8.4.2 Alternative Evaluation Techniques**

This thesis used small controlled laboratory-based experiments to evaluate performance and CCMs. The two evaluations used in this thesis relied upon short scenarios which introduced

a small number of schedule disruptions where performance was evaluated on a per scenario basis. Discrete scenario evaluations such as this, while attempting to mimic real-world operations in the selection of disruptions, are inherently artificial. Future studies should attempt to more closely mimic real operational contexts.

A more realistic evaluation would involve having participants solve a series of problems which evolve over a much longer time horizon, e.g. 2-3 hours, and would evaluate performance on a per disruption and overall basis. The timing and severity of the disruptions could be arranged so as to alternatively bore and stress the participants without the need to impose artificial time limits. A more realistic evaluation may reveal much richer set of behaviors than have previously seen.

#### **8.4.3 Interpreting CCMs**

One of the more interesting findings of this thesis is the relationship between perceived performance and self-assessed CCM. This raises a series of questions regarding the nature of workload and the what constructs it captures. Many different techniques exist for measuring workload. The TLX is a multidimensional measure which includes six different aspects of workload: Mental, Physical, Temporal, Performance, Effort and Frustration. These six aspects are not considered orthogonal and are often highly correlated. In the evaluations included in this thesis a number of different findings corresponded to a subset of these scales, providing a insight into the nature of the workload as well as CCM. Self-assessed CCMs were shown to correlate highly with perceived performance, yet were not correlated with performance. This result may indicate that an individual's perceived performance is actually their perception of how well they are doing on a task relative to their own misconception that strategic behavior yields higher performance. Viewed this way, the approach taken to meet their own internal performance criteria is vital to this measurement. If they chose an opportunistic approach they may consider their performance capped because they were not able to use a more strategic method which they assume will yield better performance. On the other hand, if they chose a strategic approach, they may feel that the solutions that they arrive at are much more likely to be good because they were able to take their time

and to thoroughly evaluate all options. Individuals adopting an opportunistic approach may correspondingly report a lower performance because the level of uncertainty they have about their performance is significantly higher than it would be had they chosen a different approach.

This interpretation might also explain the findings with regard to CCM transitions leading to higher levels of frustration. Both studies included in this thesis revealed that transitioning between CCMs is correlated with higher levels of frustration, regardless of the direction of this transition. Using the notion that individuals choose their CCM to a task based upon the current context in an attempt to match their level of effort to the task performance required a realization in the middle of the process that they are 1) either not going to be able to meet their desired level of performance or 2) are have chosen a CCM which they believe is going to provide a substandard level of performance could easily lead to higher levels of frustration. Correspondingly if they choose an inappropriate CCM and then realize that they had additional resources (often this is time) that would have allowed them to chose a CCM which they believe would have given them a better chance at improved performance, might also cause elevated frustration. This frustration is often not associated with any external features, but instead to their own ability to choose the most appropriate CCM. Sometimes, however, the frustration can be attributed to another agent or external circumstance which either increases or decreases the resources required to complete the task.

#### **8.4.4 CCMs in Other Domains**

Finally, this thesis focused on the airline operations domain, and specifically the work of airline operations managers. How does the concept of CCMs transfer to other domains? In spirit, the COCOM, from which the CCMs are derived, is domain neutral. However, the interpretation of CCMs in domains such as a flight deck or air traffic control where historically most of the work was skill based remains of practical importance. Can CCMs be transferred to domains such as this? Additionally, what are the contextual features which would correspond to the CCMs? Would the same important dimensions of subjectively



available time and number of concurrent goals continue to dominate, or would they be replaced by number of concurrent tasks and time behind schedule?

## **APPENDIX A**

### **EXPERIMENT TEST BOOKLET**

This chapter contains a copy of the experiment test booklet used to run the experiment. It includes the introductory briefing, the informed consent Form, the training outline, the post scenario questionnaires which assessed workload and CCM, the post experimental questions which assessed CWSS effectiveness and usability.

## Introductory Briefing

Thank you for agreeing to participate in our evaluation today. Today you will be asked to use an experimental prototype to solve some problems commonly encountered in day-of airline operations. Specifically we are asking you to take on the role of an airline employee whose duties include insuring the on-time arrival and departure of aircraft. Specifics of the role, including your responsibilities, will be thoroughly explained during the training portion of this evaluation.

The evaluation consists of 10 scenarios where you will be asked to solve a number of problems which arise in the publish airline schedule. Each scenario will last for 10 minutes, and only solutions entered into the system before the end of the 10 minutes will count as complete. A clock is provided as part of the experimental prototype so you will be completely aware of your time constraints. The experimental prototype has three different forms – indicated to you by different color borders, purple, green, and orange. Each of the different forms will have some aspects which are the same and some which are different from each other. You will be asked to conduct three scenarios with each prototype form. For the 10<sup>th</sup> scenario you will be able to choose which of the forms you wish to use, and may change the form at any time using controls provided.

The evaluation will include training for the specific form of the prototype we will be asking you to use, then three scenarios of 10 minutes each. Between each scenario we will ask you to complete a questionnaire which will include questions about your workload and your problem solving style. We will repeat this pattern for the other two prototype forms and will conclude with the 10<sup>th</sup> scenario where you may choose the prototype form. At the end we will ask you to complete a post-experiment questionnaire where we will ask for your overall impression of the prototype's appropriateness for the problem solving you were asked to do during the evaluation.

The prototype you are about to use has been designed and implemented for experimental purposes only. It is not of appropriate fidelity to be used in real airline operations, but we are hopeful that you will find certain features and aspects of the prototype useful.

The entire process should take between 4-5 hours. You are free to halt the experiment at any time.

School of ISyE  
Georgia Institute of Technology  
Human Subject Consent

1. **Project Title: Evaluation of a Cognitive Work Support System**
2. **Principal Investigator:** Dr. Amy Pritchett, 404-894-0199, amy.pritchett@isye.gatech.edu  
**Doctoral Student:** Karen Feigh, 404-385-0361, kfeigh@isye.gatech.edu
3. **Introduction:** You are being asked to participate in an investigation of a cognitive work support system (computer program). The purpose of this study is to better understand how people make decisions under different conditions and how to best support these different decision making modes. With this information we will be better able to design decision support systems. Please do your best to act naturally, and complete the task to the best of your ability. We would like to get the best estimate of a 'real-life' response.
4. **Procedures:** This experiment will be conducted with a standard PC and is designed to capture your interaction with the computer program during a simulated airline irregular operations recovery task under time constraints. Measurements will be made of your interaction with the computer system. You will be given a written description of the task, as well as the information needed to complete the task through the computer system. This experiment will last approximately 4-5 hours. You will be asked to participate in a total of eleven scenarios: one training scenario and ten experimental runs. The training scenario is designed to familiarize you with the nature of the task, software tools, and commands needed to retrieve information and to enter solution. The experimental runs are scenarios during which computer interaction will be observed and video recorded. After each experimental run we will ask you to complete a brief questionnaire.
5. **Foreseeable Risks or Discomforts:** Every study involves some risk. This study is considered to have low risk. Risks are no greater than those in daily work activities, such as talking on the phone or using the computer. We have attempted to control this by minimizing the time in the environment to 30-45 minutes in each session and providing breaks. You will be provided breaks during the course of the experiment; furthermore, you may request a break at any time that you desire. If you need to stop it for any reason, please let the observer know and she will freeze the simulation.
6. **Benefits:** There are no direct benefits to you however we hope to gain more insight into individual cognition, workload, and decision-making, with benefits for airline operations and decision support tools.
7. **Costs:** There is no cost to you except for your time.
8. **Compensation:** Each participant will be compensated \$50 for his/her time. If for any reason you chose to withdraw your participation before the end of the experiment you will receive compensation prorated according the amount of time you spent participating. Additionally the individual with the best performance will win a small plaque for his airline.
9. **Confidentiality:** All information concerning you will be kept private and confidential. Personal information about you will not be published or made available to any third party in any form whatsoever. Only data gathered from a completed

experiment will be analyzed and published aggregated with data from all participants and in such a form that no individual can be recognized. The videotapes will only be used for trained observers to review the behavior of the participant and to examine for unexpected events during runs that may impact the participant's performance. All raw data from this experiment, including videotapes, will be stored in a locked facility on the Georgia Tech campus. Once the analysis and documentation of this experiment are complete, the videotapes will be destroyed; electronic and paper stores of results will be archived in a locked facility within the principal investigator's Georgia Tech office or laboratory. To make sure that this research is being carried out in the proper way, the Georgia Institute of Technology IRB will review study records. The Office of Human Research Protections may also look at study records.

- 10. Injury/Adverse Reactions:** Reports of injury or reaction should be made to the Principal Investigator assisting with this research. Neither the Georgia Institute of Technology nor the principal investigator has made provision for payment of costs associated with any injury resulting from participation in this study.
- 11. Contact Person:** If you have questions about the research, call or write Dr. Amy Pritchett at (404) 894-0199, School of Industrial and Systems Engineering, Georgia Institute of Technology, 755 Ferst Ave., Atlanta, GA 30332-0205.
- 12. Voluntary Participation/Withdrawal:** You are free to withdraw your participation at any time throughout the experiment without consequence. If you choose to do so, you may leave and any data collected during the experiment resulting from your participation will be expunged.

You have rights as a research volunteer. Taking part in this study is completely voluntary. If you do not take part, there will be no penalty. You may stop taking part in this study at any time with no penalty. If you have any questions about your rights as a research volunteer, call or write:

Melanie Clark  
Office of Research Compliance  
Georgia Institute of Technology  
Atlanta, GA 30332-0420  
Voice (404) 894-6942 Fax (404) 385-2081

A copy of this form will be given to you.  
Your signature below indicates that the researchers have answered all of your questions to your satisfaction, and that you consent to volunteer for this study.

Subject's Signature: \_\_\_\_\_ Date: \_\_\_\_\_

Subject's Name: \_\_\_\_\_

Investigator's Signature: \_\_\_\_\_ Date: \_\_\_\_\_

Investigator's Name: \_\_\_\_\_

# Training

For this evaluation you will be asked to take on the slightly fictitious role of an airline operations coordinator at East Coast Airlines (ECA). In this role you have responsibility for the on time arrival and departure of all aircraft in your fleet. You are responsible for posting all delays, cancellations, swaps, and new flights. You are also responsible for handling ground delay programs as they arise. You are not responsible for crew schedule problems. You are also quite lucky in that ECA's maintenance department is usually able to work around your decisions. As such, you can feel free to swap planes without worrying about the need to check with maintenance about any outstanding MELs or current overnight maintenance assignments.

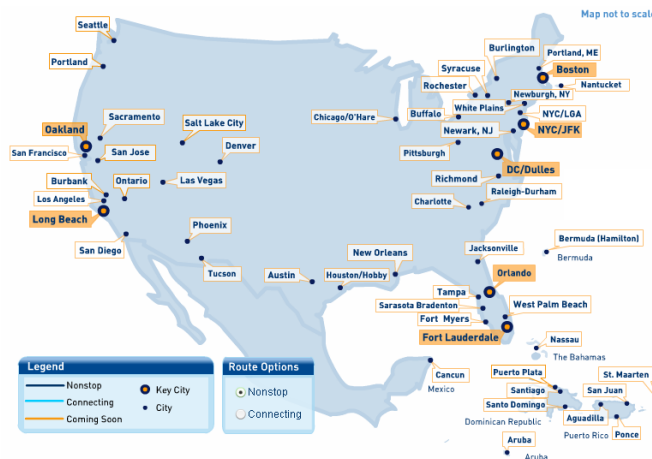
## Fleet

ECA's fleet consists of A320s and E90s. They are configured to have the following passenger capacities. Assume for the purposes of this evaluation that any aircraft can fly to any station and that if necessary any plane can be turned in 30 minutes.

- A320 – 150: 132/18
- E90 – 100: 90/10

## Destinations

- Major Hub: JFK
- Secondary Hubs: Long Beach, CA (LGB) and Boston, MA (BOS)



### Explicit Assumptions for Evaluation

- There are no spare crew (with the exception of for spare aircraft)
- Crew can be found for any spare aircraft
- None of the aircraft are maintenance critical (i.e., they can overnight anywhere, just for the night of the scenario)
- Spare aircraft are available as listed, feel free to use them as you would during your normal job. Spare crews can be found for the spare aircraft.
- Minimum turn time is 30 minutes for all aircraft types

## ***Terminology***

Stranded Passengers: Passengers who do not reach their destination that day

Average Passenger Delay: delay time averaged over all passengers on affected flights

Average Schedule Delay: delay time averaged overall all flights on the schedule

Number of Separate actions: number of discrete actions required to accomplish solution, used as a measure of complexity

## ***Purple Form Training***

### **Differences from Green or Orange**

- No computer assistance with solution generation
- Only one solution can be analyzed or stored at a time
- Less information available in the Case Organizer
- Default solution generated and implications displayed
- Only 4 dimensions of evaluation:
  - number of stranded passengers
  - average passenger delay
  - average schedule delay
  - number of separate actions

## ***Training***

- Start CWSS in the at Scenario 0
- Identify the different parts of the CWSS
  - Clock -- All times are in East Coast time
  - Viewer Section & 4 Tabs
    - Case Viewer – all information about cases is collected
    - Solution Viewer – all information about solutions is collected
    - Evaluation Viewer – all evaluation for a specific or multiple solutions is displayed
    - GDP Viewer – all information about a GDP
  - Organizer Section & 4 Tabs
    - Case Organizer – vital descriptive information about all cases
    - Solution Organizer – vital information about all solutions for a given case
    - Spare AC – list of location and availability of spare aircraft
    - Schedule – tabular list of the full schedule
  - Evaluation Criteria Button
  - Evaluate/New Solution/Execute function buttons
  - Add Case Button
  - Schedule Organizer
  - Spare AC Organizer
- Walk through how to use the CWSS
  - You can either add cases manually or they may be added to your case list by your colleagues out in the field
    - In this scenario two cases have already been added for you

- <Choose case to examine>
- <Show how it appears in the case tag>
- <Explain known issue with choosing table row>
- <Step through information on page>
  - Case Number and type
  - Affected Aircraft
  - Affected Passengers
  - Duration, Start and End time
  - Cause
  - Log/Notes – auto generated
  - Description – self generated
  - Implications panel
- <have them change cause to Other>
  - Point out Save / Undo
  - <Choose SAve>
  - Point out the sorting on the tables
- <Point out the information in the case organizer>
- <Choose to examine the GDP case>
  - Show where the GDP viewer
- Sometimes you will need to add a case
  - <Choose Add Case Button>
  - Talk about the differences between flight problems, aircraft problems and station problems
  - <Add a problem for AC N229JB>
    - If you don't choose a duration it will assume the entire time starting now.
    - <change to 500>
    - <point out how you can change the color of the thermometer plots>
- Try to solve Case 0
  - <Select Case 0>
  - <Select New Solution>
  - Talk through how to create a solution
    - Delay
    - Cancel
    - Swaps
    - New Flights
    - GDP Swaps
  - <Select Delay by 30 Minutes>
  - Pops you out to the solution list
  - In this mode you will only be able to keep one solution at a time
  - To look at it in detail, select it
  - To look at its implications <Choose Evaluate Button>
  - Decide whether you like it or not



- If not: go to either [New Solution] button or [Solution Tab and Modify] button
  - If so: go to [Execute] button
- Kicks you back to Case Organizer
  - Point out the Resolved has changed to true and the text has gone to italics
- Ask for Questions

## ***Green Form Training***

### **Differences from Green**

- Computer assistance with solution generation
- Multiple solutions can be analyzed or stored at a time
- More information available in the Case Organizer
- No default solution generated and consequently no implications are displayed
- One additional dimensions of evaluation:
  - Load factor

### **Differences from Orange**

- Computer solution generation is different (must haves)
- Manual solution generation capability
- Five dimensions available in analysis
  - Load factor
  - Number of stranded passengers
  - Average passenger delay
  - Average schedule delay
  - Number of separate actions

### **Training**

- Start CWSS in the at Scenario 0
- Identify the different parts of the CWSS
  - Clock -- All times are in East Coast time
  - Viewer Section & 4 Tabs
    - Case Viewer – all information about cases is collected
    - Solution Viewer – all information about solutions is collected
    - Evaluation Viewer – all evaluation for a specific or multiple solutions is displayed
    - GDP Viewer – all information about a GDP
  - Organizer Section & 4 Tabs
    - Case Organizer – vital descriptive information about all cases
    - Solution Organizer – vital information about all solutions for a given case
    - Spare AC – list of location and availability of spare aircraft
    - Schedule – tabular list of the full schedule
  - Evaluation Criteria Button

- Evaluate/New Solution/Execute function buttons
  - Computer Suggest Button
  - Add Case Button
  - Schedule Organizer
  - Spare AC Organizer
- Walk through how to use the CWSS
  - You can either add cases manually or they may be added to your case list by your colleagues out in the field
    - In this scenario two cases have already been added for you
    - <Choose case to examine>
    - <Show how it appears in the case tag>
    - <Explain known issue with choosing table row>
    - <Step through information on page>
      - Case Number and type
      - Affected Aircraft
      - Affected Passengers
      - Duration, Start and End time
      - Cause
      - Log/Notes – auto generated
      - Description – self generated
      - Priority
      - Responsibility
    - <have them change cause to Other and Responsibility>
      - Point out Save / Undo
      - <Choose SAve>
    - <Point out the information in the case organizer>
      - Point out the sorting abilities
    - <Choose to examine the GDP case>
      - Show where the GDP viewer
  - Sometimes you will need to add a case
    - <Choose Add Case Button>
    - Talk about the differences between flight problems, aircraft problems and station problems
    - <Add a problem for AC N229JB>
      - If you don't choose a duration it will assume the entire time starting now.
      - <change to 120>
  - Try to solve Case 0
    - <Select Case 0>
    - <Select New Solution> or <Select Computer Suggest>
      - Talk through how to create a solution manually
        - Delay
        - Cancel
        - Swaps
        - New Flights

- GDP Swaps
  - <Select Delay by 30 Minutes>
- Talk through how to ask the computer to create solutions for you
  - All the different criteria that you can specify
  - Select a few
  - <Suggest>
- Pops you out to the solution list
- In this mode you will only be able to keep multiple solutions at a time
- To look at it in detail, select it
  - <go through all of the different choices>
- To look at its implications <Choose Evaluate Button>
  - Go over evaluation criteria
- To compare implications <select multiple rows with the shift/control keys
- Sort through options
  - If certain options are not viable, then delete them with a right click
- If you want to modify solutions
  - Go to either [New Solution] button or [Solution Tab and Modify] button
- If you are happy with a solution
  - Go to [Execute] button
- Kicks you back to Case Organizer
  - Point out the Resolved has changed to true and the text has gone to italics
- Ask for Questions

## ***Orange Form Training***

### **Differences from Purple**

- Computer assistance with solution generation
- No default solution generated and consequently no implications are displayed
- No manual solution generation capability
- Multiple solutions can be analyzed or stored at a time
- More information available in the Case Organizer
- Additional dimensions available in analysis

### **Differences from Green**

- Computer solution generation is different (weights or rankings)
- Additional dimensions available in analysis

### **Training**

- Start CWSS in the at Scenario 0
- Identify the different parts of the CWSS
  - Clock -- All times are in East Coast time
  - Viewer Section & 4 Tabs

- Case Viewer – all information about cases is collected
  - Solution Viewer – all information about solutions is collected
  - Evaluation Viewer – all evaluation for a specific or multiple solutions is displayed
  - GDP Viewer – all information about a GDP
- Organizer Section & 4 Tabs
  - Case Organizer – vital descriptive information about all cases
  - Solution Organizer – vital information about all solutions for a given case
  - Spare AC – list of location and availability of spare aircraft
  - Schedule – tabular list of the full schedule
- Evaluation Criteria Button
- Evaluate/ Execute function buttons
- Computer Suggest Button
- Add Case Button
- Schedule Organizer
- Spare AC Organizer
- Walk through how to use the CWSS
  - You can either add cases manually or they may be added to your case list by your colleagues out in the field
    - In this scenario two cases have already been added for you
    - <Choose case to examine>
    - <Show how it appears in the case tag>
    - <Explain known issue with choosing table row>
    - <Step through information on page>
      - Case Number and type
      - Affected Aircraft
      - Affected Passengers
      - Duration, Start and End time
      - Cause
      - Log/Notes – auto generated
      - Description – self generated
      - Priority
      - Responsibility
    - <have them change cause to Other and Responsibility>
      - Point out Save / Undo
      - <Choose SAve>
    - <Point out the information in the case organizer>
      - Point out the sorting abilities
    - <Choose to examine the GDP case>
      - Show where the GDP viewer
  - Sometimes you will need to add a case
    - <Choose Add Case Button>
    - Talk about the differences between flight problems, aircraft problems and station problems
    - <Add a problem for AC N229JB>

- If you don't choose a duration it will assume the entire time starting now.
    - <change to 120>
  - Try to solve Case 0
    - <Select Case 0>
    - <Select Computer Suggest>
      - Talk through how to ask the computer to create solutions for you
        - All the different criteria that you can specify
        - Select a few
        - <Suggest>
    - Pops you out to the solution list
    - In this mode you will only be able to keep multiple solutions at a time
    - To look at it in detail, select it
      - <go through all of the different choices>
    - To look at its implications <Choose Evaluate Button>
      - Go over evaluation criteria
    - To compare implications <select multiple rows with the shift/control keys
    - Sort through options
      - If certain options are not viable, then delete them with a right click
    - If you want to modify solutions
      - Go to either [Suggest] button or [Solution Tab and Modify] button
    - If you are happy with a solution
      - Go to [Execute] button
    - Kicks you back to Case Organizer
      - Point out the Resolved has changed to true and the text has gone to italics
  - Ask for Questions

## NASA task Load Index TLX

We are interested not only in assessing your performance but also your experiences in the different conditions. Basically I want to examine your "workload".

Since workload is something experienced individually, it can be difficult to estimate. Because workload may be influenced by many different factors, we would like you to evaluate several factors individually rather than lumping them into a single evaluation of overall workload. This set of six rating scales was developed by NASA. Please read the descriptions of the scales carefully. If you have a question about any of the scales, please ask us about it, as it is important that they be clear to you. I will leave the descriptions on the table for reference during the rest of the experiment.

Please evaluate the scenario by marking each scale at the point that matches your experience. Each line has two endpoint descriptors that describe the scale. Note that "performance" goes from "good" on the left to "bad" on the right. Please place an X **anywhere** along each scale between a pair of tick marks. Consider each scale individually. These ratings are an important part of the experiment and I appreciate your efforts.

### **Rating Scale Definitions**

<b>Title</b>	<b>Descriptions</b>
MENTAL DEMAND	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
EFFORT	How hard did you have to work (mentally and physically) to accomplish your level of performance?
PERFORMANCE	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
FRUSTRATION LEVEL	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

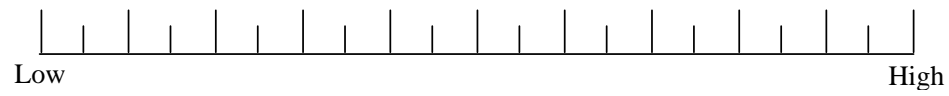
Participant: \_\_\_\_\_  
Scenario: \_\_\_\_\_  
Run: \_\_\_\_\_

Please circle the **line** which indicates the workload level you experienced:

**Mental Demand**



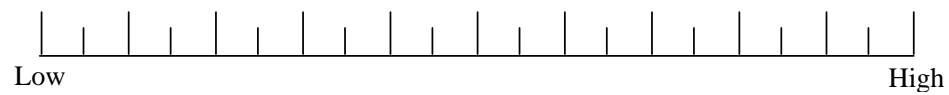
**Physical Demand**



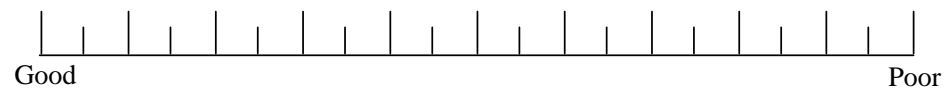
**Temporal Demand**



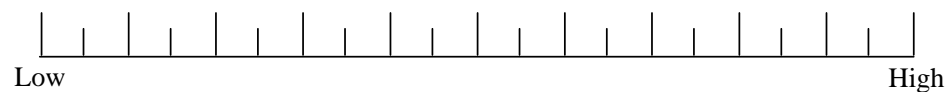
**Effort**



**Performance**



**Frustration**



Participant: \_\_\_\_\_  
Scenario: \_\_\_\_\_  
Run: \_\_\_\_\_

### **CCM Questionnaire**

Answer the questions to the best of your ability by circling the answer which most accurately describes your feelings during the majority of the experiment time.

- 1. After completing an action how did you evaluate its effect on the system?**
  - A. Just checked to see if system seemed to be better than before
  - B. Examined the immediate (or obvious) effects
  - C. Examined the main (select group of important metrics) effects
  - D. Detailed evaluation of the feedback including previous developments, expected outcomes and unexpected results
- 2. Overall, would you say that you:**
  - A. Had inadequate time
  - B. Had just adequate time
  - C. Had enough time
  - D. Hand plenty of time
- 3. Would you say that you felt:**
  - A. Extremely rushed
  - B. Rushed
  - C. Slightly pressed for time
  - D. No time pressure at all
- 4. How many different goals were you considering?**
  - A. One
  - B. One or two (possibly competing)
  - C. A few nested or ordered goals
  - D. Several
- 5. How much of your past experience did you take into consideration?**
  - A. None
  - B. A little
  - C. A decent amount
  - D. All of it
- 6. How far into the future did you evaluate the consequences of your actions?**
  - A. Immediate response only
  - B. An hour down the road
  - C. Several hours down the road
  - D. Through the end of the day



Participant: \_\_\_\_\_

Scenario: \_\_\_\_\_

Run: \_\_\_\_\_

**7. Thinking back on your previous activity, which best describes your mode of execution?**

- A. Automatically carried out the steps of a chosen plan
- B. I observed my actions on the environment
- C. I noted whether the effects of my actions were what I anticipated or not
- D. Mixture of A, B and C

**8. Thinking back on your previous activity, how would you describe the way you chose what actions to do when?**

- A. Randomly – whatever popped into my head
- B. Based on the dominant effects of the computer interface or the situation
- C. Based on a predefined procedure/ plan
- D. Based on a personal prediction for what needed to happen to achieve a goal

Participant: \_\_\_\_\_  
 Scenario: \_\_\_\_\_  
 Run: \_\_\_\_\_

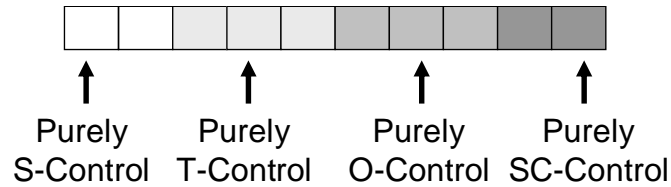
## Contextual Control Modes

We are interested not only in assessing your workload but also your experiences in the different conditions. Basically I want to examine the way you make decisions. Since the way each person makes decisions is different, it can be difficult to measure. Cognitive scientists have developed a set of “contextual control modes” which categorize common decision making styles. This scale of four different categories is presented below. Please read the descriptions of the categories carefully. If you have a question about any of the categories, please ask us about it, as it is important that they be clear to you. I will leave the descriptions on the table for reference during the rest of the experiment.

<b>Title</b>	<b>Current Problem</b>	<b>Descriptions</b>
S-CONTROL	Optimally solved with respect to the overall goal	S Control is characterized by consideration of the global context. A person in a strategic control state is thinking more about the impact of any current decision on the overall goal, than the impact of any current decision on the current problem.
T-CONTROL	Solved with respect to the overall goal	In T-Control, a person’s evaluation of the current situation goes beyond the dominant needs of the present, but the choice of action is still governed by the current situation. Often T-Control is characterized by situations where a person’s decisions are based on procedures, rules or a plan, which may not lead to an optimal solution to the overall goal, but will lead to a good solution to both the current problem and the overall goal.
O-CONTROL	Solved without thinking about the overall all goal	O-Control corresponds to the case when a person’s decision is chosen from the current situation in response to the current problem alone. Often O-Control is characterized by situations where a person is not concerned about achieving the overall goal, but instead on achieving a solution to the current problem.
SC-CONTROL	Possibly solved, possibly not solved	Sc-Control corresponds to the case where a person’s decision is completely unpredictable or random. People using sc-control are in a state of mind where there is no thinking involved; only a blind trial-and-error.

Participant: \_\_\_\_\_  
Scenario: \_\_\_\_\_  
Run: \_\_\_\_\_

**Please place an X anywhere on the scale to indicate which mode you felt you were in during the majority of the task just concluded.**



**Please circle your answer:**

Did you feel as if you transitioned from one contextual control mode to another at any point during the run?

YES

NO

If so, please answer the following questions:

Which mode did you first transition from?

S-Control

T-Control

O-Control

SC-Control

Which mode did you first transition into?

S-Control

T-Control

O-Control

SC-Control

What triggered your transition?

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Please briefly describe your problem solving strategy:

Participant: \_\_\_\_\_

***Post Experiment Questionnaire***

Age: \_\_\_\_\_

Male or Female (circle one)

Do you current work in airline operations:: Yes      No

If yes:

Number of years in current position: \_\_\_\_\_

Number of years working in airline operations: \_\_\_\_\_

Is the computer system you work with primarily:

Text-based                      Graphical (i.e. Gantt Charts showing lines of flygin)

Were any of the tasks noticeably more difficult than the others?

YES                      NO

If so, please list any reasons why you believe this was so:

Were any of the tasks noticeably easier than the others?

YES                      NO

If so, please list any reasons why you believe this was so:

---

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### General Satisfaction

Overall how useful was the new tool?

Very Useful    Somewhat Useful    Neutral    Not Useful    Useless

If the tool were available to you in your daily work would you use it?

Yes                                      No                                      Maybe

*Comments:*

What was your favorite feature of the tool?

What was your least favorite feature of the tool?

What capability/function would you add to the tool?

### CCM Mode Specific Questions

Did you notice a difference between the different forms (green, orange, purple)?

Yes                                      No                                      Maybe

*Comments:*

Did you have a favorite mode, or did you prefer more than one mode depending on the circumstances?

Did the different tool modes make sense, i.e. could you imagine how one mode might be more useful in certain circumstances?

Yes

No

Maybe

*Comments:*

Please explain under what circumstances you think each mode is most appropriate?

Green

Purple

Orange

If you were to be given a final version of this tool, do you feel you would switch between the different forms?

Never

Seldom

Sometimes

A Lot

Frequently

### **Memorability**

Were there any features that you forgot how to access?      Yes      No

*Please list any you can remember*

How easy were features of the tool to remember?

Very difficult

Difficult

OK

Easy

Very Easy

### **Learnability**

How easy was it for you to learn the tool?

Very difficult      Difficult      OK      Easy      Very Easy

Did you feel that you were adequately trained on the tool?

Completely Inadequately      Inadequately      Adequate      Fairly Well      Very Well

How much time do you feel would be appropriate to train someone to use this tool?

### **Errors**

Did the design of the tool cause you to make errors?

Yes, all the time      Yes, some times      Maybe      No, not really      No, never

If you found yourself making mistakes when using the tool, how could we change the design to minimize this from happening in the future?

### **Efficiency**

Do you feel you would be more productive if you were given a final version of this tool?

No      I doubt it      Possibly      Probably      Yes

Do you feel the tool would allow you to solve problems more quickly?

No      I doubt it      Possibly      Probably      Yes

Any other comments:

## APPENDIX B

### SCENARIO BRIEFINGS

#### ***B.1 Scenario 1, Time: 1300-1310***

TIME LINE:

- 1300** Call from Maintenance. "The ready time on N612JB down in Aruba (AUA) is now 1550"
- 1305** GDP notification. "A GDP has been announced for BNA. It is now in your case list"
- 1307** Call from Maintenance. "Maintenance up in JFK, here. We just got the part they need for AC N585JB so the new ready time has moved from 1400 to 1500."

#### ***B.2 Scenario 2, Time: 0600-0610***

TIME LINE:

- 0600** Call from Maintenance. "Call from C-check maintenance facility, Aircraft N623JB won't be ready today, probably will be good to go tomorrow."
- 0602** Call-1 from Gate Agent. "Call from gate agent. Pilot on AC 197 found a warning light on in his preflight. Maintenance has been called, we'll get back to you when we know more."
- 0607** Call-2 from Gate Agent. "Call from gate agent again. Just a few minor things, AC197 should be ready to go at 8am, in about 113 minutes."

#### ***B.3 Scenario 3, Time: 1010-1020***

TIME LINE:

- 1010** Call from Maintenance. "AC N583JB is going to be late coming out of a maintenance check in Orlando. New ready time is 1445. Sorry."
- 1012** Call from Dispatcher. "Inbound Flight 52 with lots of connections is scheduled to arrive late. In about 50 minutes or so if ATC doesn't mess with them."
- 1016** Call from Maintenance. "Call from Maintenance. Flight 705 is having trouble with the pressurization system. Got a few guys on it, probably going to take a few hours. Posting a ready time is 1315"



#### ***B.4 Scenario 4, Time: 1245-1255***

TIME LINE:

**1245** GDP notification. “An emergency landing has closed one of Boston’s runways. ATC has responded by issuing a GDP for the airport effective starting in 30 minutes.”

**1248** Call from Dispatcher. “Flight 346 coming out of Sarasota (SRQ) is going to be delayed because of a fuel supply issue. Should be air born at 1415, about an hour late.”

#### ***B.5 Scenario 5, Time: 1245-1255***

TIME LINE:

**1245** Call from Maintenance. “Call from Maintenance at JFK. Aircraft N229JB had a ready time of 1500, will now be ready at 1600.”

**1250** GDP notification. “Call from ATC. A WX related GDP has been issued for FLL from 1500-1700 with an arrival rate of 15. It will appear in the system shortly.”

#### ***B.6 Scenario 6, Time: 0935-0945***

TIME LINE:

**0935** GDP notification. “Due to wild fires in the area a GDP has been released for Palm Beach (PBI) starting at 1000”

**0940** Call from Dispatcher. “Late arriving crew caused FL 370 to depart 80 minutes late - arriving in 20 minutes.”

#### ***B.7 Scenario 7, Time: 1700-1710***

“A GDP is set to begin in two hours [1900-1830] and will affect the main hub at JFK.”

#### ***B.8 Scenario 8, Time: 0815-0825***

“A snowstorm set to hit the Washington DC region in 6 hours will reduce the airport capacity by 80% for the following 8 hours.”

#### ***B.9 Scenario 9, Time: 1435-1445***

“GDP at MCO due to wild fires in the area. Shifting winds have begun to reduce visibility and a GDP will be released soon.”

***B.10 Scenario Users Choice Scenario 10, Time 10:55-11:05***

- 1055** Call from Dispatch. “FL620 is arriving 70 minutes late due to ATC delays for volume.”
- 1059** Call from Gate Agent. “AC N229JB is missing paperwork from the last flight crew. We are tracking it down now and expect to be ready to go in about an hour.”
- 1102** Call from maintenance. “AC N579JB has a flat tire, we are on it. New ready time is 1400.”

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